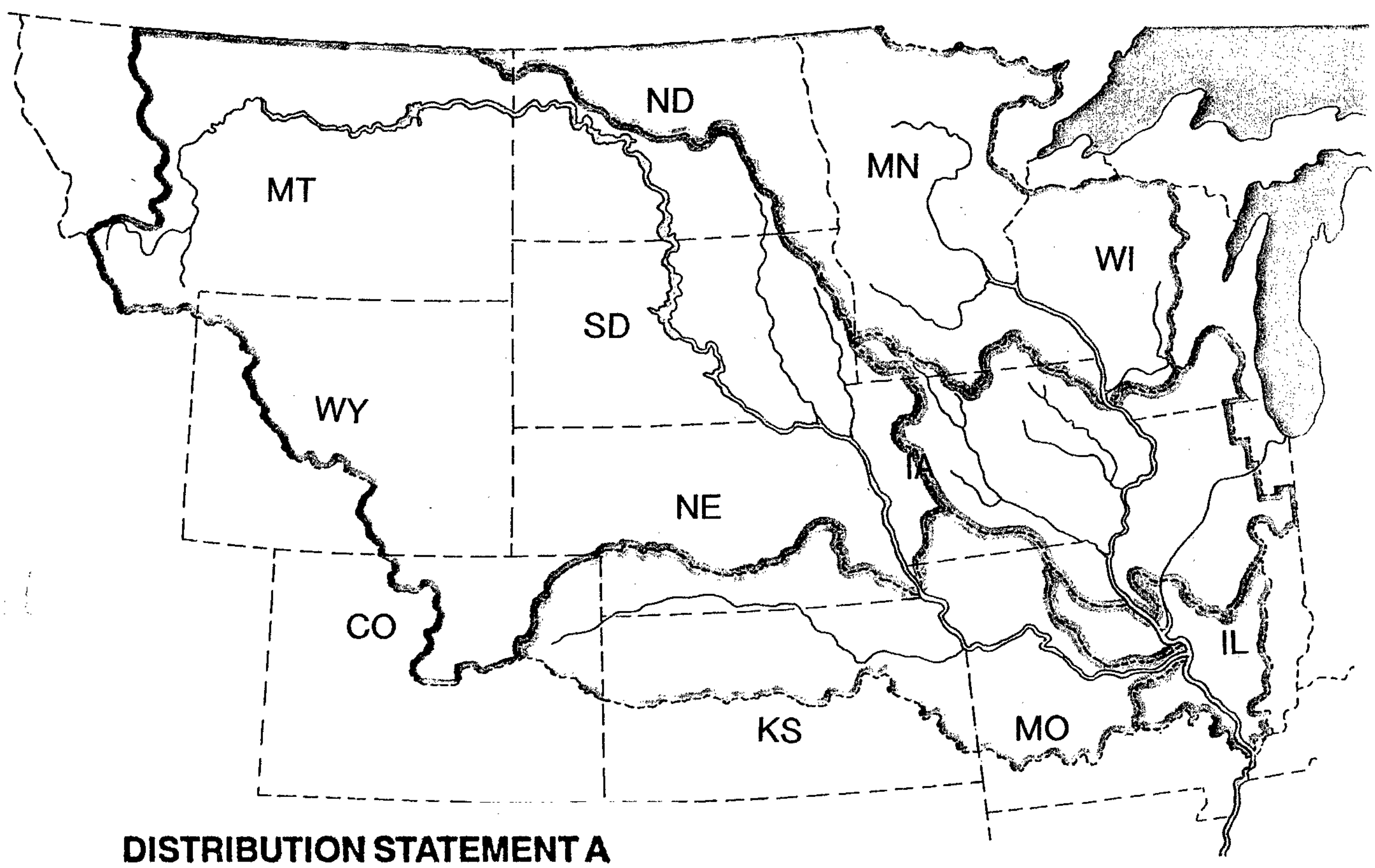
The Great Flood of 1993 Post-Flood Report

Upper Mississippi River and Lower Missouri River Basins



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Main Report

September 1994

US Army Corps
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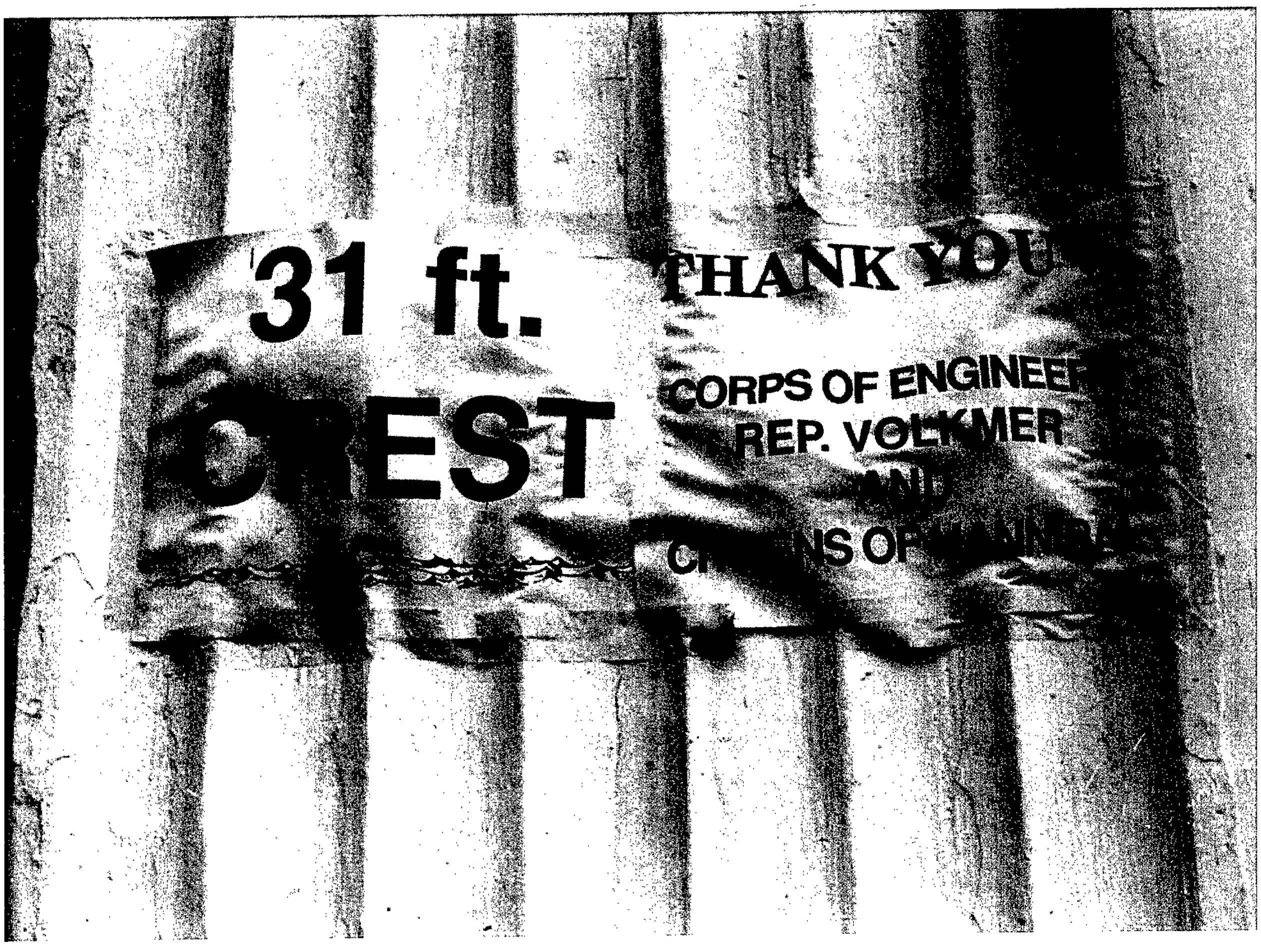

Business owners in the historic section of downtown Hannibal, Mo., show their thanks for the Corps-built flood control project just completed before the Flood of 1993. The signs were mounted on a number of buildings to show where a 31-foot crest forecast by the National Weather Service would have been. The actual crest was near 32 feet.

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The Flood of 1993 was an unusual and significant hydrometeorological event that desvastated the Midwest. The 1993 was distinctive from all other record floods in terms of its magnitude, severity, damage and the season in which it occurred. The present report contains information about the flood and the general involvement of the Corps in the flood-affected areas. An appendix which provides detailed flood descriptions, data, and information on Corps flood cotnrol, flood fight and post flood activities is included for each of the district offices involved: Appendices A (St. Paul District) and Appendices B (Rock Island District) cover the Mississippi River basin above Lock and Dam no. 22; Appendix C (St. Louis District) concerns the Mississippi River basin below Lock and Dam no. 22; Appendix D (Omaha District) and Appendix E (Kansas City District) cover the Missouri River Basin.

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US Army Corps
of Engineers
North Central Division

The Great Flood of 1993 Post-Flood Report

Upper Mississippi River and Lower Missouri River Basins

Main Report

September 1994

Abstract

The Flood of 1993 was an unusual and significant hydrometeorological event that devastated the Midwest. The flooding of the Mississippi and Missouri rivers resulted in the death of 47 people and caused between $15 to $20 billion in damage. The 1993 flood was distinctive from all other record floods in terms of its magnitude, severity, damage, and the season in which it occurred.

Excessive precipitation during April through July 1993 produced severe or record flooding in a nine-state area in the upper Mississippi River basin. Excessive precipitation also affected the Missouri River basin, adding to the flood's areal extent in three states. The rain storms that caused the flood of 1993 were unique both in the size of the flooded area and in the fact that the storms resulted in the cresting of the Mississippi and Missouri rivers within the same week. As a result of severely high water along the Mississippi River below Dubuque, Iowa, barge traffic was suspended from late June until mid-August 1993.

Although, typically, floods occur in the spring, this flood occurred throughout the summer along the Mississippi and Missouri rivers. Flooding and water levels above the flood stage continued through the middle of September in many regions along the Mississippi River. In Hannibal, Missouri, the Mississippi River remained above flood stage for more than 6 months.

Corps reservoirs along the upper Missouri River were able to store much of the excess runoff in Montana and North and South Dakota. However, on the Missouri River, downstream of Omaha, Nebraska, the reservoirs couldn't accommodate the record runoff. Portions of the Missouri River therefore remained above flood stage for several months. On the Mississippi River, only three reservoirs had significant storage capacity above St. Louis, Missouri. These three reservoirs are located in Iowa and are operated by the Rock Island District for flood-reduction purposes. The Corps reservoirs were able to reduce the Mississippi River stage downstream of Keokuk, Iowa. Because of the prolonged runoff periods, the maximum crest reductions from the operation of Coralville, Saylorville, and Red Rock Reservoirs, amounted to 11 inches at Quincy, Illinois, and Hannibal, Missouri.

Even with these three reservoirs, the Flood of 1993 was in excess of a 100-year flood and in some areas, perhaps even a 500-year flood. The media brought this disastrous event into living rooms all across the country and broadcast it to the world almost on a daily basis. No other natural disaster in U.S. history affected or touched so many lives for so long a duration as did the Midwest Flood of 1993.

Flooding from this event caused major highways, bridges, and rail lines to be closed for long periods. Officials from these entities now will be redesigning their facilities to protect against future floods of this magnitude. Navigation was shut down on the Mississippi River for up to 52 days, closing a main transportation artery to the Midwest.

In the aftermath, major efforts were carried out to restore the lock operations on the Mississippi River. Many wastewater and water supply facilities were disrupted or even totally shut down. Officials of these facilities are redesigning them to provide greater flood protection. Cost-effective measures for hazard mitigation are expected to be incorporated into the repair cost of damaged public facilities.

Effective mitigation measures now need to be implemented in order to reduce the future loss of life and property. The impacts and lessons learned as a result of the Flood of 1993 are expected to provide a planned approach to ensuring significant reductions in flood damage resulting from flood events of this extraordinary magnitude.

Preface

"A disaster in slow motion" is how one person described the Flood of 93. It is an appropriate phrase for a flood that lasted several months, broke previous flood-stage records, and was unmatched by any other flood disaster in the United States in terms of public and private property damage. Nine states in the Midwest were catastrophically impacted. Highway, rail, and inland-waterway transportation were paralyzed during and after the flood.

High flood stages were not the only aspect of the flood that made it so disastrous. In most areas, the river stayed at extremely high levels for weeks, saturating and severely testing levees along the banks. The duration factor prolonged the time that highway, railroad, and barge traffic was disrupted, costing the Nation millions of dollars.

A rare combination of meteorological patterns produced a convergence zone over the upper Midwest between the warm, moist air from the Gulf of Mexico, and the cooler, drier air from Canada. This weather pattern stalled in the area until the end of July, causing unusually heavy precipitation. The ground was already saturated, the result of a wet fall in 1992 and spring 1993 snowmelt, and the additional rain went directly into runoff.

On the Mississippi River, from the Quad Cities area in Iowa and Illinois., to below St. Louis, Mo., this flood broke records set by the major floods of 1973 and 1965. In some areas, it was 6.3 feet higher than the highest level previously recorded. Record flows and stages also occurred on the lower Missouri River.

The area between the Quad Cities and St. Louis is primarily rural and agricultural. Most of the Mississippi River bank is lined with earthen levees that were built to allow farmers to till the rich bottom soil behind them. Although the levees were originally built to protect only farmland, towns have sprung up in the areas protected by the levees.

The Corps of Engineers became involved in these gradually over the years by strengthening and raising some of them. Maintenance remained a local responsibility. These levees were no match for this flood as most were built to withstand a 25- or 50-year flood. They were being faced with 100- to 500-year flood discharges.

While the levees in most parts of this region are earthen agricultural levees, the Corps has constructed flood walls and levees to protect larger towns such as Rock Island and Quincy, Ill., Hannibal and St. Louis, Mo., Topeka and Kansas City, Kan., and Kansas City, Mo. Many of these projects were built as a direct result of the floods in 1951, 1952, 1965, 1969, and 1973.

Several Corps flood-control reservoirs played key roles in reducing flood damages. Most of these reservoirs reached record stage levels, and some of them experienced spillway discharge for the first time since they were constructed. Corps reservoirs in Iowa reduced the peak of the flood by .9 foot in Quincy and .2 foot in Hannibal. Reservoirs in the Missouri River basin reduced the peak of the flood in Sioux City, Iowa, by 6 feet; Omaha, Neb., by 5 to 8 feet; and about 3 feet from Nebraska City to the mouth near St. Louis.

Most of the locks and dams on the Mississippi River were inoperative during the flood and several of the locks were completely under water.

The Corps was very active in the flood fight, distributing more than 31 million sandbags and miles of plastic sheeting to help local communities protect themselves. Engineers trained for flood fighting were stationed at critical areas on the rivers, providing invaluable technical assistance. The Corps worked in partnership with federal, state, and local agencies, the National Guard, and local drainage districts to keep the flood from causing more damage than it did.

Estimated flood damage so far totals $15 to $20 billion including $6.5 billion in crop damage, 20 million acres of farmland damaged, 47 lives lost, 74,000 people evacuated, 72,000 homes damaged, 39 of 229 federal levees damaged, 164 of 268 non-federal levees damaged, 879 of 1,079 private levees damaged, and about 200 pumping stations and several water-treatment plants were flooded and disabled.

After flood waters receded, the Corps immediately began the enormous undertaking of repairing damaged levees under the Public Law 84-99 program, which authorizes the Corps to repair damaged flood-control works such as federal and non-federal levee systems that qualify. It was imperative to repair the levees in preparation for possible spring flooding in 1994. Flood waters damaged an estimated 78 percent of the non-federal and private levees along the Mississippi and Missouri rivers.

As a result of the flood, two different floodplain-management studies have been undertaken. These studies will look at floodplain use, floodplain management, and flood control along the Missouri and upper Mississippi rivers.

Acknowledgements

The main report and its five appendices are the result of the dedicated efforts of a number of employees of the Corps of Engineers. When the North Central Division accepted the task of preparing the report, it was under the condition that it be ready for distribution by Oct. 1, 1994. We met the milestone only because of the dedication, motivation and determination of the team at work. The team was composed of a great number of people, the listing of which would be too overwhelming. However, because of their extraordinary contributions, some team members deserve special recognition.

Project Managers for appendices A, B, C, D, E, respectively:

Judy DesHarnais (St. Paul District)	Anna Crickmer (Omaha District)
Shirley Johnson (Rock Island District)	Susanna Gehrt (Kansas City District)
Avenant Melidor (St. Louis District)	

The following team member, too, deserve special recognition.

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Rock Island District:

The Rock Island District received support from Judith Flint (Buffalo District) and Lan Do (Mobile District).

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David Matthews	Rex Rhoades	Robert Pearce	Kim Penner
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Others contributors include David Legg (Ohio River Division), Jack Hurdle and David Barretta (Memphis District), and Malcolm Dove and Tim Loyde Ethridge (Lower Mississippi Valley Division). Larnie Blaylock, printing specialist, and Leonard Trzeciak, illustrator, of the Chicago District, also assisted in the report preparation and printing. From Headquarters, U.S. Army Corps of Engineers (USACE), assistance was provided by Earl Eiker and Richard DiBuono.

Special kudos to Denise Yale (Rock Island District) who went the extra mile in writing much of the Main Report, and designed and edited it. Harry Gieg (Huntington District) contributed to the final proofing and editing. The cover of the report was designed by Loren Carey (Rock Island District). In the North Central Division, Donald Leonard, John Kangas, Robert Occhipinti, Jose Ordonez, Mari Cronberg have reviewed and edited all six components. Joseph Raoul, overall project manager, was assisted by Harry Krampitz who coordinated the reviews, printing, and report distribution.

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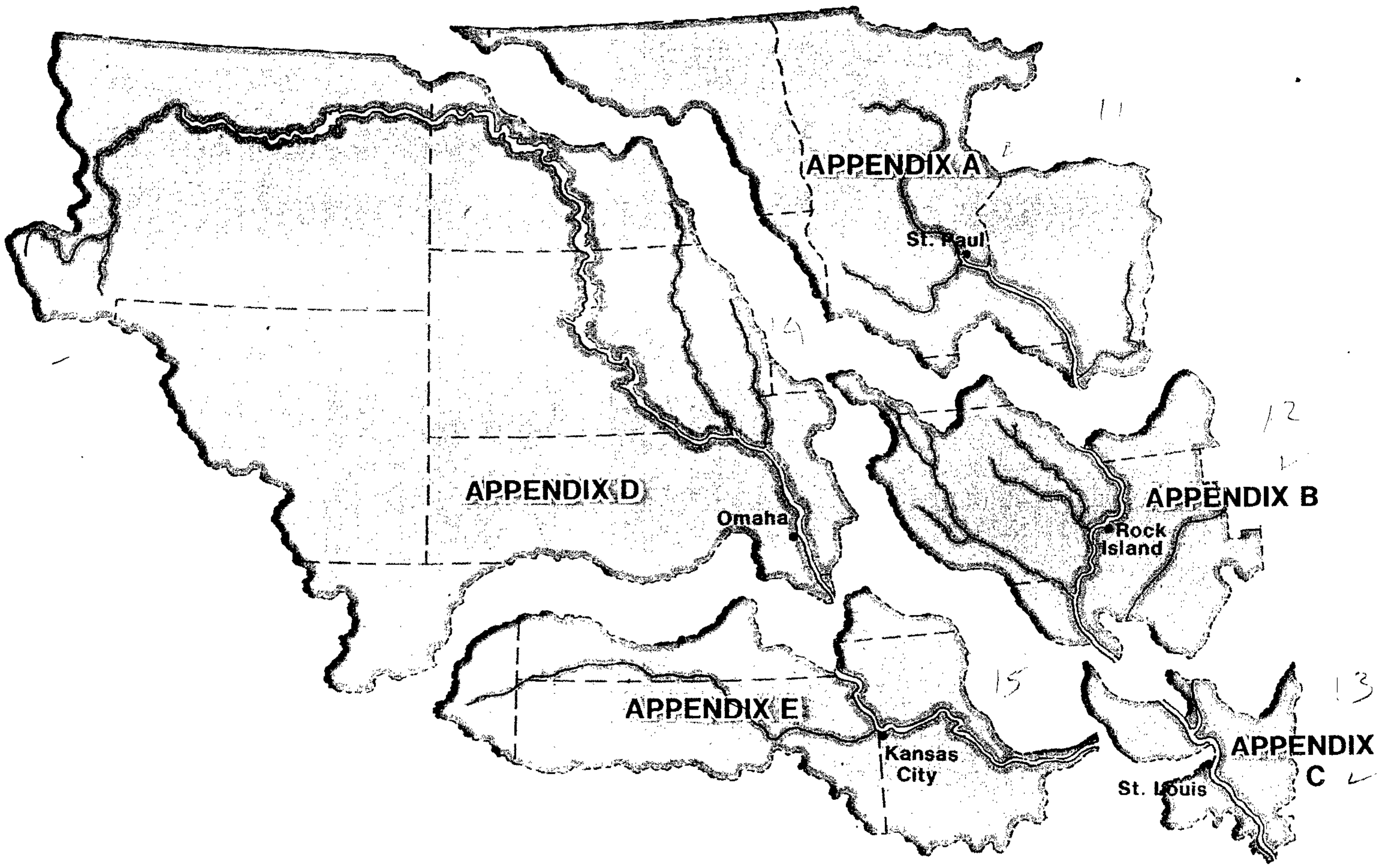


APPENDICES (Separately bound)

A. St. Paul District Report

B. Rock Island District Report

C. St. Louis District Report

D. Omaha District Report

E. Kansas City District Report

Flood control project in Canton, Mo., and Lock and Dam No. 20 on the Mississippi River.

Section I

Introduction

Authority

This report has been prepared in accordance with ER 1110-2-240 with specific authority by a Headquarters, U.S. Army Corps of Engineers, letter to the Division Engineer, North Central Division, dated Aug. 18, 1993, subject, Post Flood Report, Mississippi River Basin Flooding. The North Central Division was assigned the task to prepare the main post-flood report and its appendices. The Missouri River and the Lower Mississippi Valley divisions participated in the effort.

Purpose and Scope

The present report contains information about the flood and the general involvement of the Corps in the flood-affected areas. An appendix which provides detailed flood descriptions, data, and information on Corps flood control, flood fight, and post-flood activities is included for each of the district offices involved:

Appendices A and B concern the Mississippi River basin above Lock and Dam 22;

Appendix C concerns the Mississippi River basin below Lock and Dam 22; and,

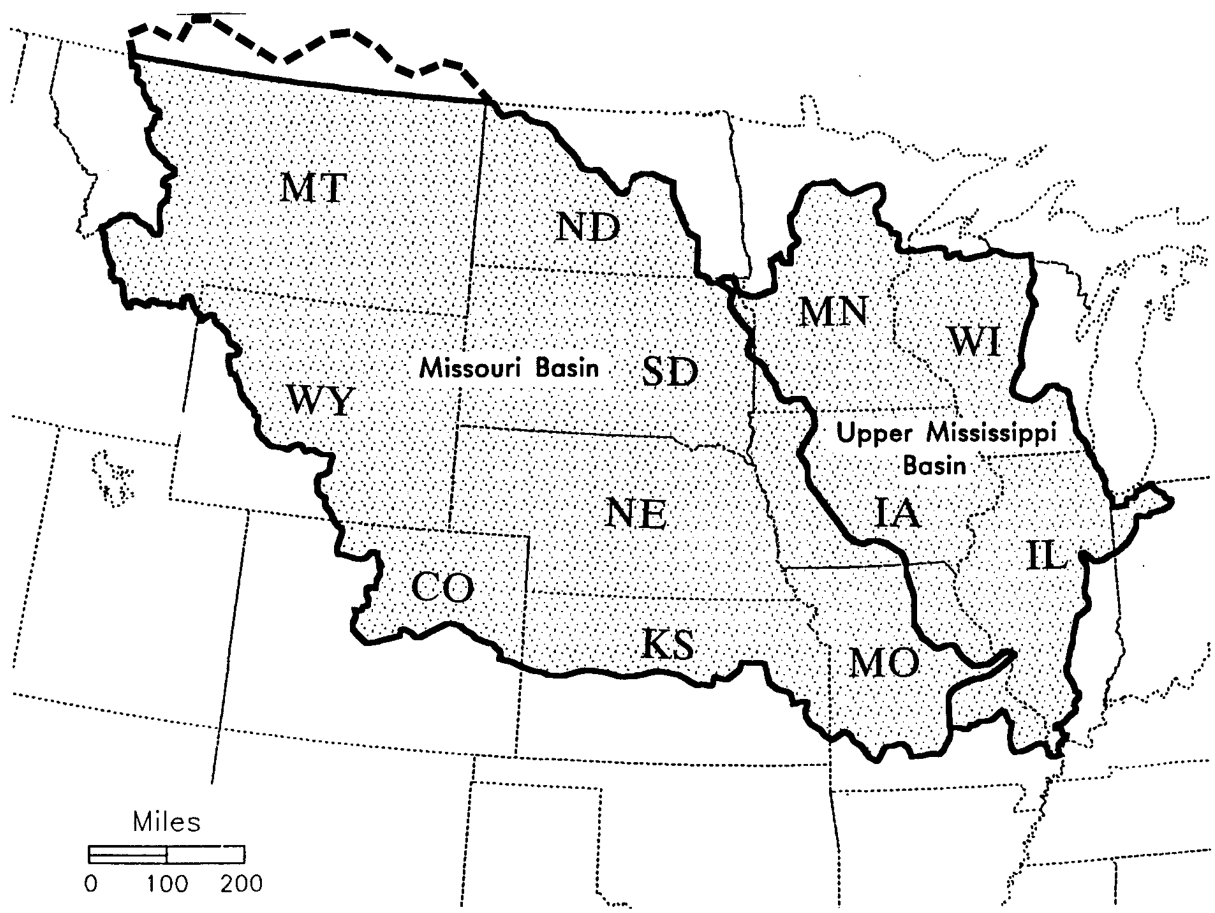


Figure 1. Areal extent of the Missouri and upper Mississippi river basins.

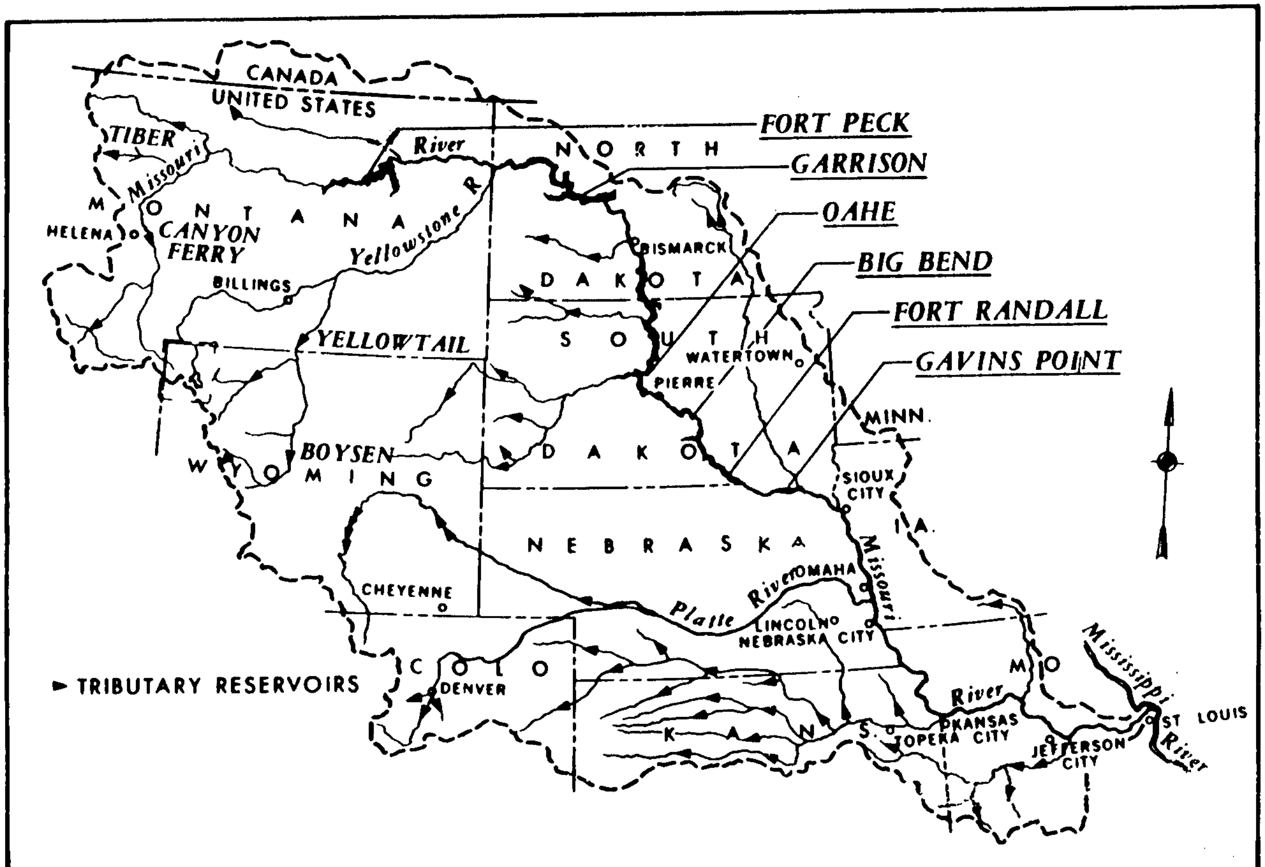


Figure 2. Missouri River Basin.

Appendices D and E concern the Missouri River basin.

The audience for this report is the Corps of Engineers and the general public. The report is intended to document information that will be of use to professionals inside and outside the agency in connection with future planning programs associated with reservoir water-control management, flood-plain management, and emergency management.

Description of the Mississippi and Missouri River Basins

The Mississippi River rises in the lake and forest country of north-central Minnesota, near Itasca, and flows north, east, and then south through timbered landscape to Minneapolis-St. Paul. At this point, it leaves the northern woodlands and lakes and meanders southward past fertile prairies, villages and cities. Along the way, numerous tributaries join the Mississippi River and add to its flow.

The Mississippi River basin drains 41 percent of the land area of the continental United States and covers all or part of 31 states. Starting with its headwaters in the Lake Itasca region, the river flows 2,350 miles to its mouth in the Gulf of Mexico. The floodplain along the main stem of the Mississippi River varies in width from approximately three quarters of a mile to more than 14 miles and averages about 5 miles wide. The river, which originally followed a meandering course, now has a fixed course with much of its adjacent farmland now protected by levees.

The drainage area of the Mississippi River has six major sub-basins: the upper Mississippi, Mis-

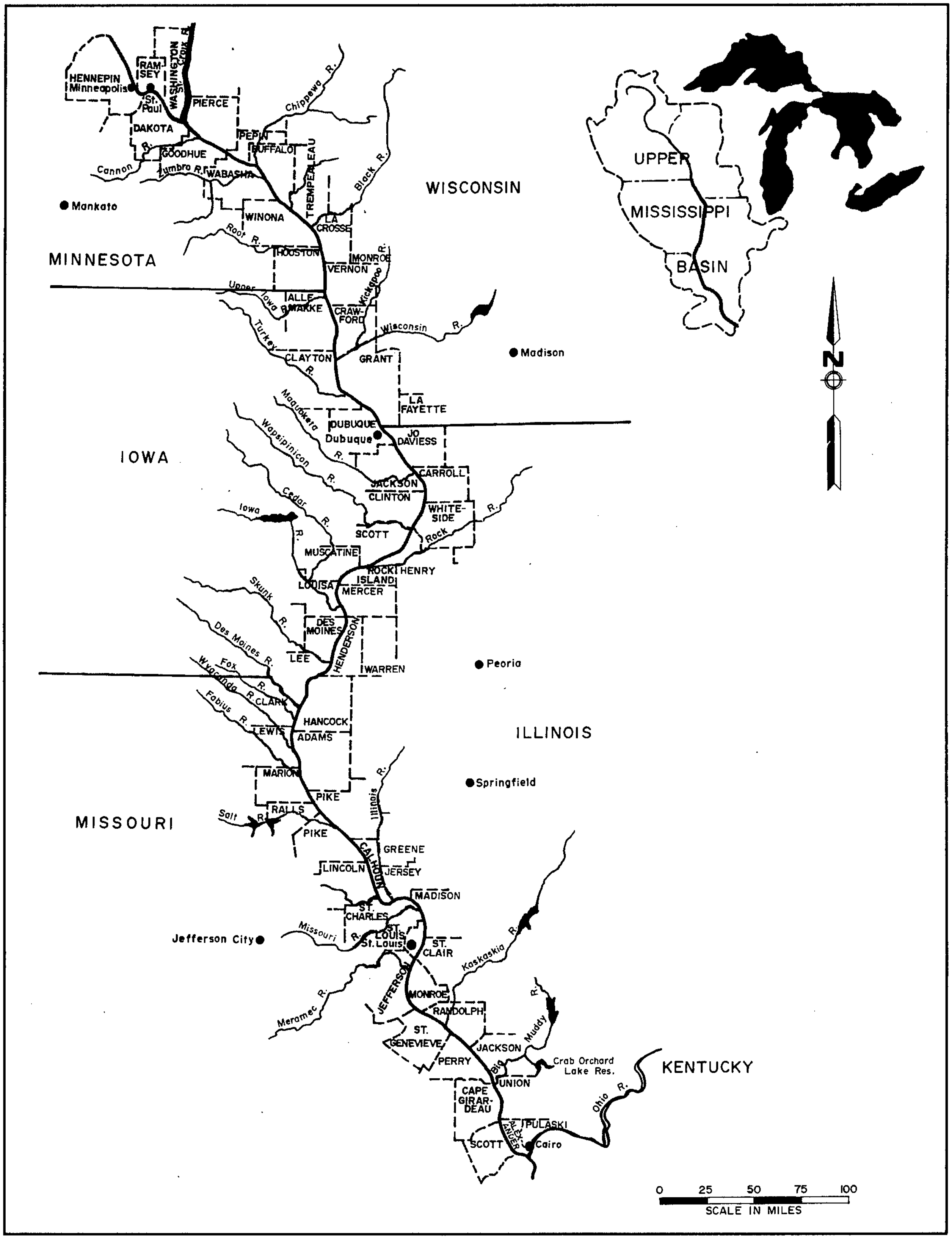


Figure 3. Upper Mississippi River basin main stem.

souri, Ohio, Arkansas, White, and the lower Mississippi. Each sub-basin contributes flow to the main-stem Mississippi River in varying amounts. Historically, the Missouri and Arkansas rivers have contributed greater amounts of sediment, while the Ohio River contributes the greater percentage of water discharge and the least concentration of sediment. The total drainage area of the Mississippi River is approximately 717,600 square miles at its confluence with the Ohio. Approximately 523,000 square miles of this area are drained by the Missouri River. Other major tributaries of the Mississippi River include the Salt, Illinois, Kaskaskia, Meramec, Big Muddy, St. Francis, Rock, Des Moines, Iowa, Wisconsin, St. Croix, and Minnesota rivers.

Miles of levees line the banks of the Mississippi River, and many of these proved inadequate against the unprecedented flood that devastated large areas in the states of Minnesota, Wisconsin, Iowa, Illinois, and Missouri. In many locations, this flood broke the record levels set by the major floods of April 1965 and April 1973.

Besides the main stem of the Mississippi River, other basins in the flooded areas include the lower Missouri River and its tributaries, the Des Moines River, Iowa River, Illinois River and its tributaries, and the Rock River.

The Missouri River rises along the Continental Divide in the northern Rocky Mountains and flows generally easterly and southeasterly to join the Mississippi River near St. Louis, Mo. The river drains approximately 9,715 square miles of Canada and 513,000 square miles or one sixth of the contiguous United States. Its area includes all of Nebraska and parts of Missouri, North Dakota, Kansas, Colorado, Wyoming, Montana, South Dakota, Iowa, and Minnesota.

The Missouri River, which drains 74 percent of the upper Mississippi River basin, contributes only 42 percent of the long-term average annual flow of the Mississippi River at St. Louis. Hydrologically, the Missouri River basin is divided into two portions, with demarcation at Sioux City, Iowa. The upper basin contains 314,600 square miles and the lower portion contains 208,100 square miles.

The Missouri River basin contains numerous reservoirs and impoundments constructed by different interests for flood control, irrigation, hydroelectric power production, recreation, and water supply. The most significant of these structures have been constructed by the Bureau of Reclamation and the Corps. The Bureau projects were constructed for flood control, irrigation, and power productions. The most significant authorized flood-control projects constructed within the basin are the six main stem Missouri River dams constructed by the Corps.

The Missouri River levee system was authorized by the Flood Control Acts of 1941 and 1944 to provide protection to agricultural lands and communities along the Missouri River from Sioux City, Iowa, to the mouth at St. Louis, Mo. The levees were planned to operate in accord with the six main-stem dams.

The Pick-Sloan Plan federal levees were constructed between Omaha and Kansas City. From Kansas City to St. Louis, most levees were privately built and did not follow the set-back concept of the plan. These non-federal levees are designed for varying degrees of protection.

Plate 2 shows the outline of the Mississippi River basin with the 1993 flooded area shaded in.

Section II
General Meterology

Antecedent Conditions

Although record rainfall amounts of were not broken in the upper Mississippi River basin in the fall of 1992, November and December were well above normal. In November, rainfall totals were two to three times the normal amount.

Precipitation during the winter of 1992-1993 and spring of 1993 was above normal, and temperatures were below normal throughout the lower Missouri River basin. Persistent rains and early snowmelt culminated in high spring runoff. With the exception of some areas in Colorado and western Kansas that had below normal precipitation, the period of April and May was wet and cool.

A wet-weather pattern persisted over the upper Midwest for about six months. This pattern resulted from an eastward-flowing jetstream that extended from central Colorado northeastward across Kansas to northern Wisconsin. Because of this jetstream, a weather-front convergence zone formed across the upper Midwest during the spring and summer of 1993. Moist, warm air from the Gulf of Mexico was drawn northward along this jetstream, where it collided with cooler air masses drawn out of central Canada.

This combination of extreme conditions generated frequent occurrences of prolonged and excessive precipitation over the upper Mississippi River basin, leading to the destructive floods.

In the first seven months of 1993, more than 20 inches of rain fell over most of the flood-affected area, with more than 40 inches of rainfall occurring in areas of northeast Kansas and east-central Iowa.

There has been some speculation that the 1993 floods might have been associated with greenhouse gas-induced global warming and related circulation changes. The quantitative research that has been done suggests, however, that central North America will have a drier climate as a result of global warming, although the most recent hypothesis is that highly variable and extreme conditions could result at least initially. Thus, both extreme flood and extreme drought are consistent with the global warming theory, and the 1993 floods cannot be conclusively connected with this phenomenon.

Similarly, the volcanic eruption of Mt. Pinatubo in June 1991 has likely affected global mean temperatures, but the exact nature of the changes in circulation that might have resulted from the eruption are not known. It is therefore difficult to link the floods to the eruption. As with global warming, considerable study and analysis will be required before any conclusions can be drawn regarding the impact of the eruption on global circulation and specific rainfall patterns.

Preliminary tests using the current El Nino Southern Oscillation-related (ENSO) sea-surface temperature anomalies in the tropical Pacific in a numerical climate model at the National Meteorological Center show a response that replicates the observed precipitation and temperature anomalies to a noticeable extent. This suggests that the current long-lived ENSO event probably contributed to the large-scale atmospheric features associated with the floods. Similar, though less intense, features were also observed in 1992, however, with no significant flooding occurring in the areas affected in 1993. Moreover, Wayne Wendland of the Illinois State Water Survey, showed that, for eight ENSO events of varying intensity since 1952, the associated mean precipitation over the upper Mississippi River basin differed by less than 10 percent from the long-term average during the period 1961-1990.

In any case, there were certainly other contributing factors to the 1993 floods. It will take more detailed analysis, involving both observations and coupled ocean/atmosphere global circulation models, to get a definitive understanding of the role of sea-surface temperatures in the tropical Pacific in the recent extreme precipitation events.

Description of Storms

One of the unusual aspects of the floods of 1993 was that they were not the product of one

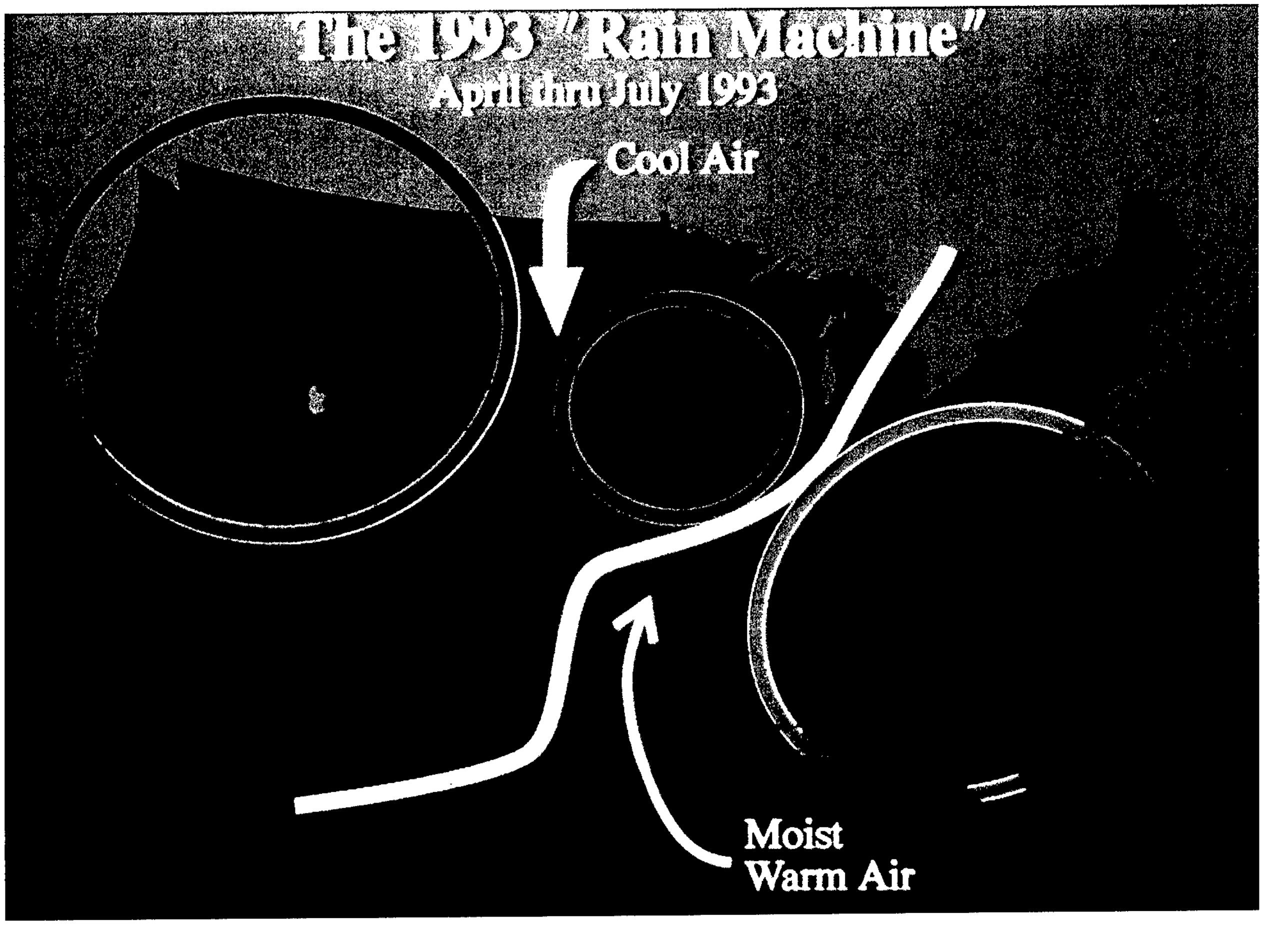


Figure 4. Dominant weather patterns over the United States for April through July.

single, large-scale event, such as an intense synoptic scale cyclone or snowmelt and runoff. Instead, they were the result of numerous smaller scale and shorter duration, but more locally intense, thunderstorm events that were much more widespread and longer lasting than individual events of this kind usually are.

The flood-producing rainfall events were typically the result of thunderstorms repeatedly forming and moving over the same area, a phenomenon sometimes referred to as the "train effect." Storms of this kind usually form either right along or just to the north or northwest of a slow-moving or stationary front aligned parallel or nearly parallel to the upper air winds. Weather disturbances moving along the surface front will force the warmer air to the south or southeast of the front to rise over the cooler air to the north or northwest. In an area determined by the air mass and circulation characteristics, the warm air will rise to a level where it will begin to rise freely and rapidly due to convection, generating thunderstorms that then move with the upper winds. In these situations, it's common for thunderstorms to form in and then move over the same areas, one after the other, creating the "train effect."

The alignment of the surface fronts and the jet stream during the summer of 1993 were highly favorable for the formation of the kind of weather disturbances that set off the "train effect" thunderstorms. The intensity of these storms, once they formed, was then enhanced by the extreme nature of the temperature contrasts across the region and the intensity of the jet stream.

By the summer of 1993, the mean position of the jet stream was firmly established over the northern portion of the Mississippi River basin with a southwest-northeast orientation.

Major flooding began after a period of particularly heavy rainfall in mid-June in southwest Minnesota and northwest Iowa. This included record flooding on the Minnesota River.

Following a short dry period, the area experienced a prolonged siege of heavy rainfall from late June through July 11. This included extreme precipitation on July 9 in Iowa, which resulted in record flooding on the Raccoon and Des Moines rivers. Just as the crests from these two rivers reached Des Moines, a relatively small, convective pocket dumped several inches of rain on the crests, rapidly boosting the river levels and flooding a water-treatment plant in Des Moines.

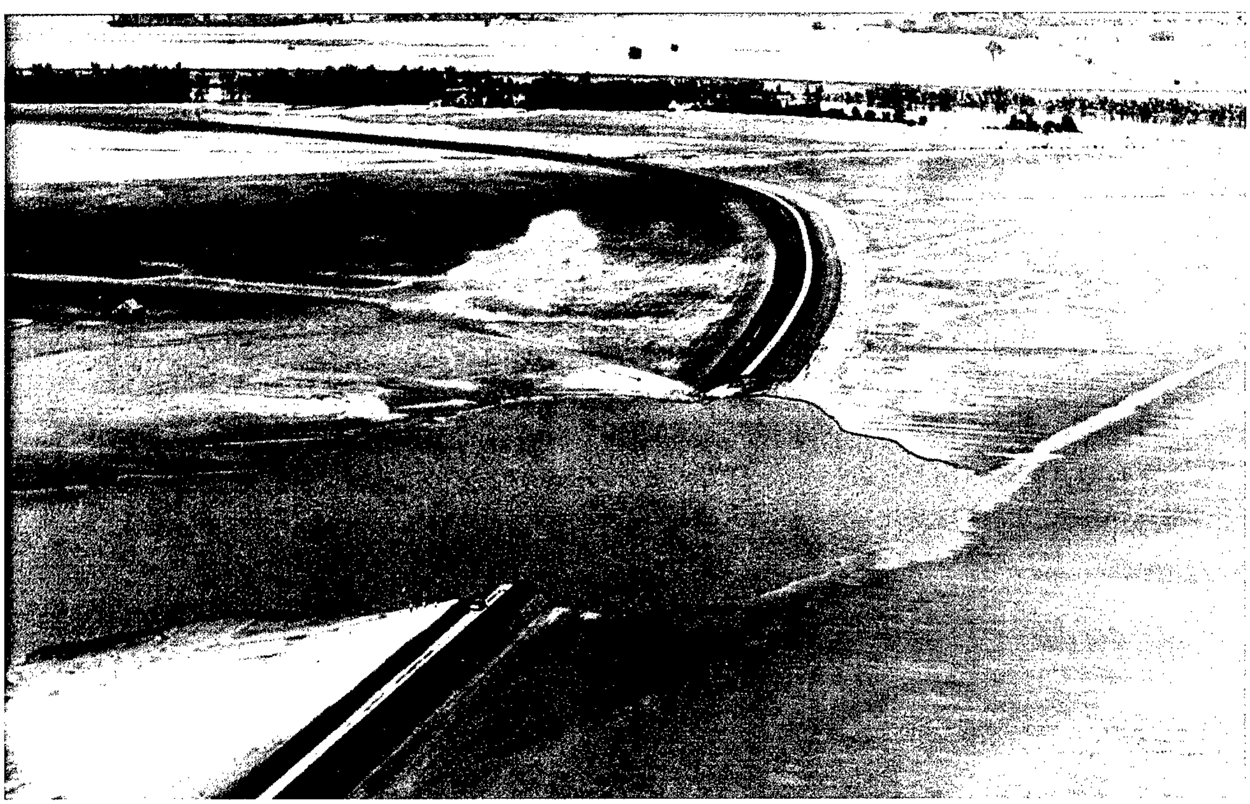
This rainfall event also led to record flooding on portions of the lower Missouri River and combined with the crest already moving down the Mississippi, causing record river stages from the Quad Cities area, through St. Louis, and as far south as Thebes, Ill.

Another major precipitation impulse occurred July 21 to 25. The heaviest rains were focused farther south than the earlier events, with especially heavy rain falling over eastern Nebraska and Kansas, leading to second major crests on both the Missouri and Mississippi rivers.

Chronology of Storms

The following is a chronology of some of the more notable storms that occurred over the region from June to August. In June and July, rain fell somewhere in the region every day.

June 16-18—Two to seven inches of rain fell throughout southern Minnesota, northern Iowa, and southwestern Wisconsin, areas with already saturated soils. The heaviest rain fell directly over the Minnesota River. These storms caused the flooding on the Minnesota and Mississippi rivers in Minnesota and the Chippewa and Black rivers in Wisconsin that began the entire Mississippi River flood event. Further precipitation during the next few days caused flooding in and near Black River Falls, Wis., which led to a partial failure of



Levee breach at L470-460 near Elwood, Kan.

Sandbagging on the Missouri River near Rocheport, Mo.

the dam. It also caused flooding in other tributary basins in Wisconsin, namely, the Chippewa, Buffalo, Trempealeau, and Wisconsin river basins.

June 25—Additional localized rainfall in central Iowa contributed to the runoff at the three Iowa reservoirs—Saylorville, Coralville, and Red Rock.

June 27—Several areas recorded up to 4 inches of rainfall. The Iowa River basin below Coralville Lake was one of the areas that received heavy precipitation. Three to 5 inches fell over the Papillion Creek basin in Omaha, Neb.

June 28—Additional rainfall around Iowa City, Iowa, and the upper Mississippi River below Dubuque, Iowa, continued to aggravate the situation.

June 29—An additional 2 inches of rain fell on Iowa City and the upper Mississippi River during the night. Seven inches of rain occurred over the Lake Okoboji and Spirit Lake area in Iowa.

July 1—Near Quincy, Ill., an additional 2 to 5 inches of precipitation fell. Flood waters continued to rise along a 300-mile stretch of the Mississippi River on July 2. On July 6, the Mississippi River crested for the second time at Dubuque. The second crest continued downstream to the Quad-Cities, Keithsburg, Ill., and Hannibal, Mo., and new records were established.

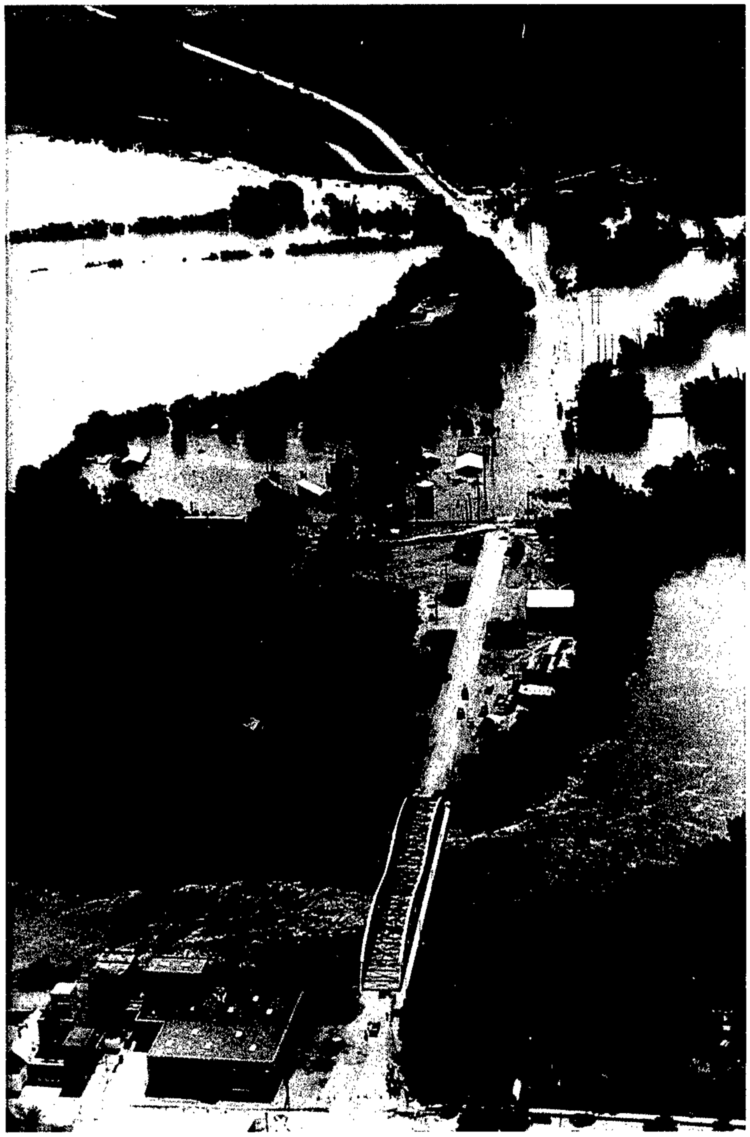
July 2-5—Five to 7 inches of rain was reported in an area from Mitchell to Madison, S.D.

July 3-9—Six to ten inches of rain fell in various locations in Iowa, Kansas, and Missouri. Rain on July 3 caused the third episode of significant flooding in Marshall, Minn., in two months.

July 4-5—This storm was a significant event, producing a large amount of rainfall over southern Iowa. It produced a total of 4 to 8 inches of rain across a 250-mile long path from Taylor County in southwest Iowa, northeastward through Oskaloosa, Marengo, Cedar Rapids, and Dubuque.

July 7-8—Additional rainfall occurred on the Des Moines River basin. The rivers throughout central Iowa had not receded from the storm on July 4 and the three major reservoirs in the area were at capacity. Strong thunderstorms moved into central Iowa before sunrise on July 8 and rapidly traversed eastward across Iowa and into Illinois. A second set of thunderstorms developed over west-central Iowa later in the afternoon and slowly moved along the same path as the morning storms. By the time these storms weakened on July 9, 3 to 9 inches of rain fell in an uninterrupted 275-mile long band from the Nebraska border at Onawam eastward through Guttenburg, Iowa. Up to 8.5 inches of rain fell on the Des Moines River basin at Jefferson, Iowa. Marshalltown, Iowa, received up to 3 inches while 1 to 2 inches of rain fell over various parts of eastern Iowa and western Illinois. The Mississippi River crested for a third time at Camanche, Iowa, and the Quad-Cities also crested again.

The runoff from the July 4 and July 8 storms caused record or near-record peak discharges on the Iowa, Skunk, Raccoon, and Des Moines river basins. The flood peaks from these tributaries entered the Mississippi River at about the same time the flood peak from the late June storm in the northern basins reached Keokuk, Iowa. The crest approached St. Louis from the north and joined high water coming in from the west down the Missouri River, an event that has never occurred since record keeping began.



Minnesota River at St. Peter, Minn, State Hwy. 99

July 11—Moderate to heavy rainfall fell in central Illinois.

July 13—Heavy rainfall occurred in the Des Moines area.

July 15-16—Up to 7 inches of rain fell in eastern North Dakota and western Minnesota. These storms caused flooding in the upper reaches of the Minnesota River basin in Minnesota and the James River basin in North Dakota.

July 17—Two to 5 inches of rain was reported in about a one-hour period over the Mill Creek basin near Cherokee, Iowa.

July 18—Light to heavy precipitation occurred across Iowa, Wisconsin, and Illinois. Portions of the Cedar River basin received up to an additional 5 inches of rainfall. Heavy rains caused flooding on the Baraboo River in Wisconsin.

July 22-25—Up to 13 inches of rain fell in parts of Nebraska, Kansas, North Dakota, Missouri, Iowa, and Illinois, resulting in peak stages along the Missouri River south of Omaha, Neb. On July 24, an additional 4 inches of rain fell on southern portions of Iowa and Illinois. The Mississippi River began to rise again and the Illinois Waterway also went above flood stage. There were unofficial reports of up to 16 inches of rainfall in southeast Nebraska.

July 31—Significant precipitation occurred in eastern Iowa. Iowa City and areas south reported 2 to 3 inches of additional rain.

Aug. 10—Up to 4 inches of rain fell near Iowa City.

Aug. 11—Additional precipitation occurred throughout the area with up to 5 inches falling in the Iowa River and Cedar River basins. Flash flooding occurred along the Iowa River near Marshalltown and Tama, Iowa, in the same area that experienced flooding previously.

Aug. 20—Six inches of rain occurred in two hours over the southern Black Hills of South Dakota.

Aug. 21—Seven to 10 inches of rain fell near Wolf Point, Mont.

Rainfall Data

The National Climate Data Center reported July to be among the three wettest months since 1885 in eight of the nine states in the upper Mississippi River basin, with July being the wettest month ever recorded for the Dakotas, Montana, and Iowa. It was the second wettest month for Kansas and the third wettest for Missouri and Nebraska. More than 30 inches of rain fell in central Kansas and northern Missouri from April through July. July rainfall totals were at or near record levels in every state, except Colorado, which had the second driest July of record.

The unprecedented precipitation that fell throughout the basin during the summer months was caused by an unusual weather pattern that developed in mid-June and remained for nearly two months.

Precipitation amounts across the region for the first seven months of 1993 were substantially greater than normal in most areas, and more than twice the normal in some places. Most of this excess precipitation fell as rain in the warmer months; the first three months of the year had near normal precipitation, mostly in the form of snow. The situation began to set up for the summer months in April and particularly May.

Precipitation in April was about twice the normal in the southern half of Wisconsin, and the northern two-thirds of Illinois. Five inches or more of rain fell over a wide area, including southeastern Minnesota, the southern half of Wisconsin and most of Illinois.

In May, heavy rainfall occurred in Iowa and Missouri with a monthly total of 8 inches; 4 to 6 inches of rain fell in Minnesota and Wisconsin; and 4 inches fell in Illinois. One and a half to two times the normal amount of precipitation fell in areas most directly impacted by the heavy rains to come. This was particularly the case in southwestern Minnesota, where two storms in succession between May 6 and 8 brought the first of the damaging floods, left the soil saturated, and set the stage for the more widespread flooding a month later.

In early June, the atmospheric circulation pattern became established and persisted well into July. The heavy rains and associated flooding began soon after the circulation pattern formed, with the first and most serious event occurring on June 16 and 17 across southern Minnesota, northern Iowa, and southwestern Wisconsin. The month saw two to two and a half times the normal precipitation in southern Minnesota and Wisconsin (5 to 13 inches), northern Illinois (5 to 13 inches), and all of Iowa (7 to 11 inches).

For the month of July, Iowa recorded up to six to 15 inches of rain, southern Minnesota and southern Wisconsin had 4 to 9 inches and the northwestern half of Missouri received 6 to 30 inches. Several counties in northwestern Missouri recorded as much as eight to ten times the normal rainfall during July. Six to 10 inches of rain occurred in various locations in Kansas. The most intense storm period occurred on July 22 to 24 on

Sny Levee, south of Quincy, Ill.

the 1961-1990 normals for the seven-month period.

A review of all flood-producing storms in Minnesota since 1970 indicates that this storm, as widespread and intense as it was, was not the most widespread nor the most intense such storm for the state as a whole. Three storms have covered larger areas, all in central or northern Minnesota, and a number of storms have generated greater point rainfall totals.

What makes the storm of June 16-17, 1993, stand out is its unique combination of storm alignment, antecedent conditions, and river conditions. This combination made the difference between what might otherwise have been a series of local flash-flood or sub-basin events and the major river flood that this storm produced.

small tributaries of the Missouri River upstream of St. Joseph in northeast Kansas, southeast Nebraska, northwest Missouri, and southwest Iowa. There were unofficial reports of up to 16 inches of rainfall in southeast Nebraska.

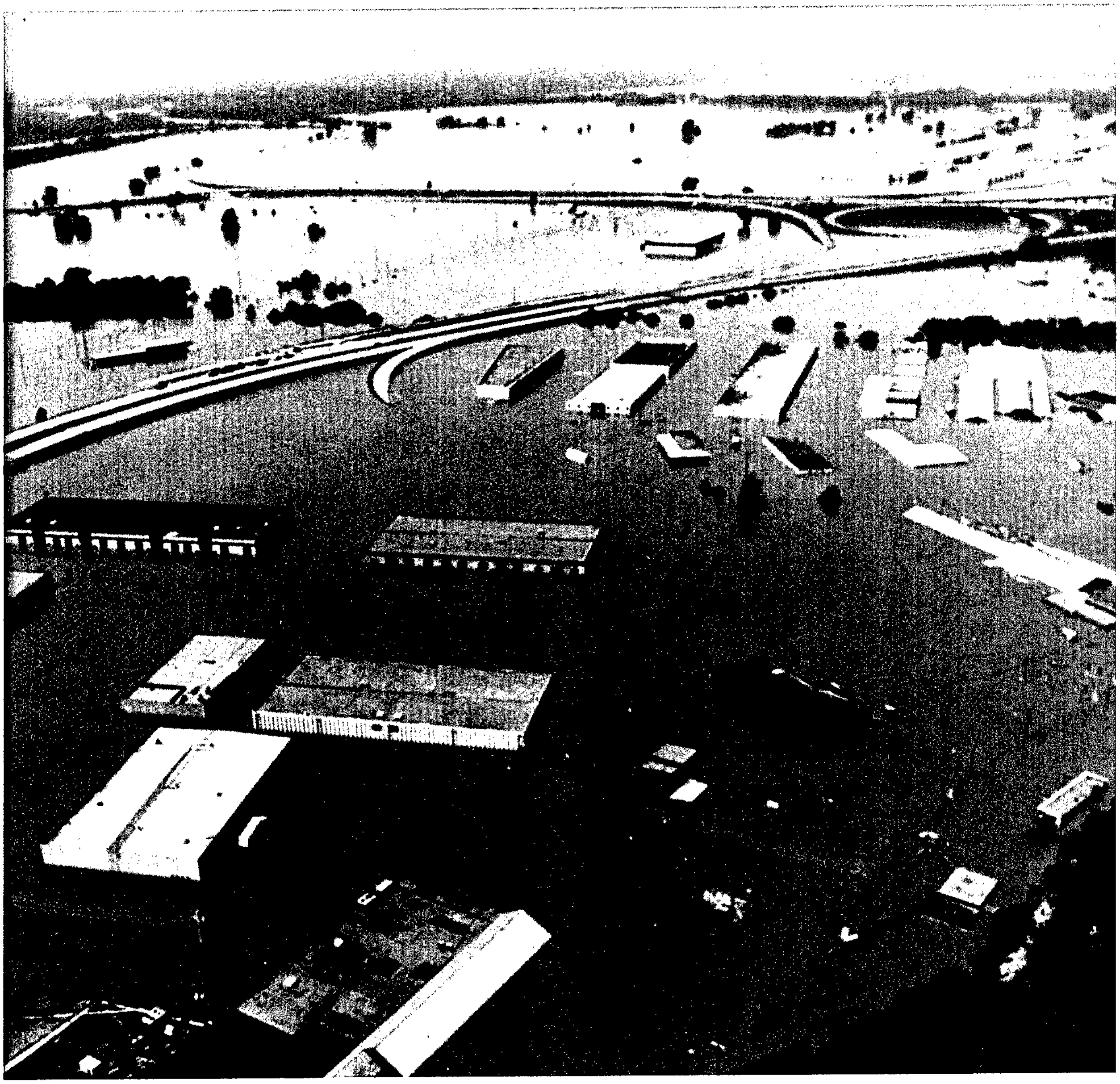
Rainfall totals for August show that Iowa had totals ranging from 4 to 14 inches, with the heaviest occurring in the northeastern part of the state. In Illinois, the totals ranged from 4 to 6 inches and Wisconsin's totals were about 4 inches. Minnesota and Missouri recorded between 4 and 8 inches.

Comparison with Previous Storms

The 1993 spring weather was wetter than usual, with rainfall averaging twice the normal amount over much of the upper Mississippi River basin. Total precipitation for January through July 1993 was 140 percent or greater than normal in most of the areas in the upper Mississippi River basin. Total rainfall for January through July 1993 was 121 to 221 percent higher when compared to

The storm of July 1951 produced the flood of record on the Kansas River and major flooding on the downstream Missouri River. A constant movement of warm air from the gulf of Mexico met cool air from the north and led to widespread storms at frequent intervals. Following a two-month period of above-normal precipitation, large amounts of rainfall occurred over the Osage-Marais des Cygnes River and Kansas River basins during a five-day storm period of July 9-13. In May, rainfall over Kansas averaged 6.4 inches. The average rainfall of 9.6 inches over Kansas in June was the greatest monthly average rainfall of record at that time. Light rains during the first part of July kept the soils well saturated. Precipitation during July 9-13 amounted to as much as 18.5 inches in certain areas. The areal distribution was 15.5 inches over 1,000 square miles, 13.1 inches over 5,000 square miles, 11.5 inches over 10,000 square miles, and 9.5 inches over 20,000 square miles.

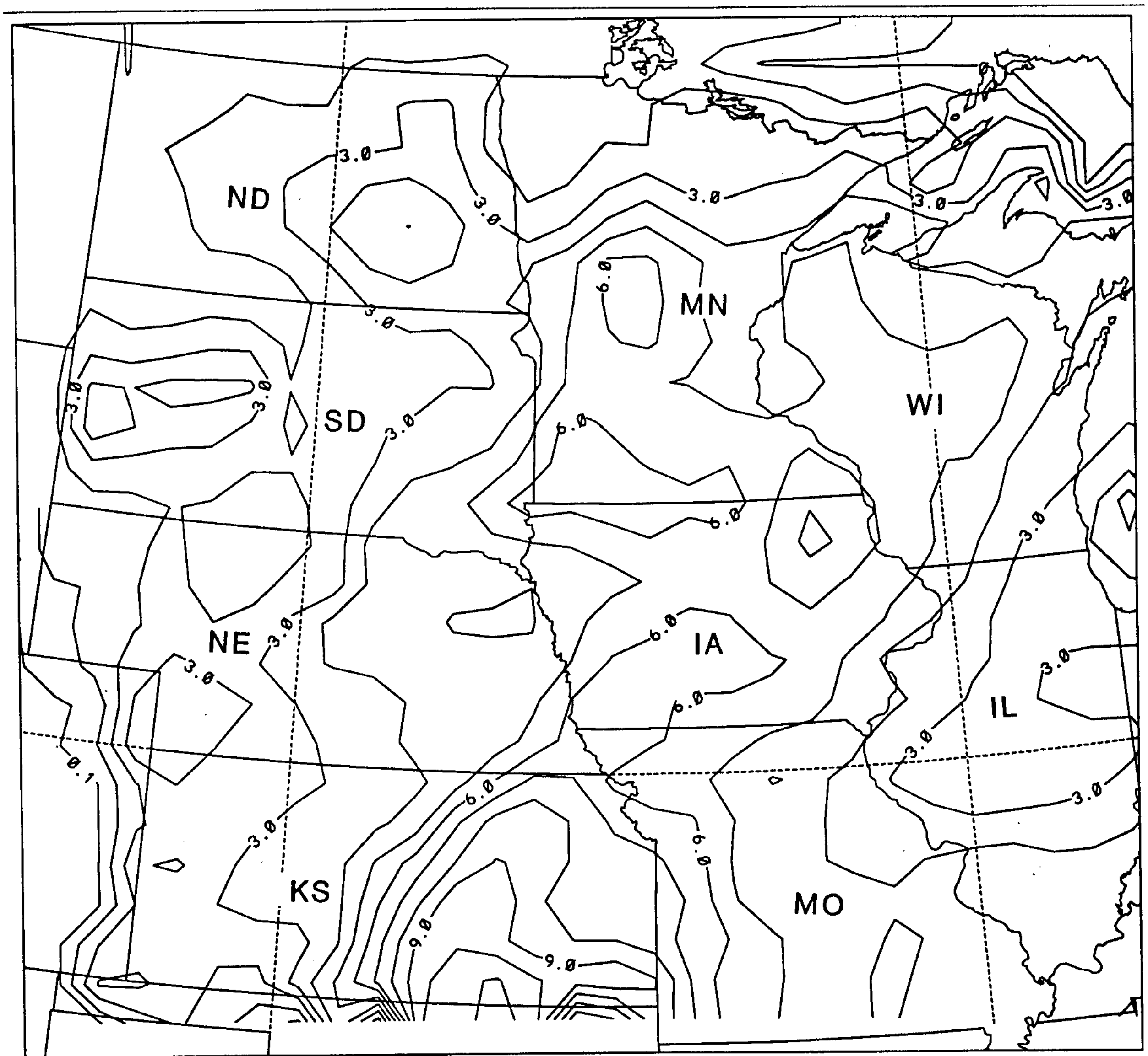
The storm of May 1935, characterized by intense precipitation over the Republican River, is of interest because of its relatively high intensity over



Flooding at Riverside, Mo., on the Missouri River.

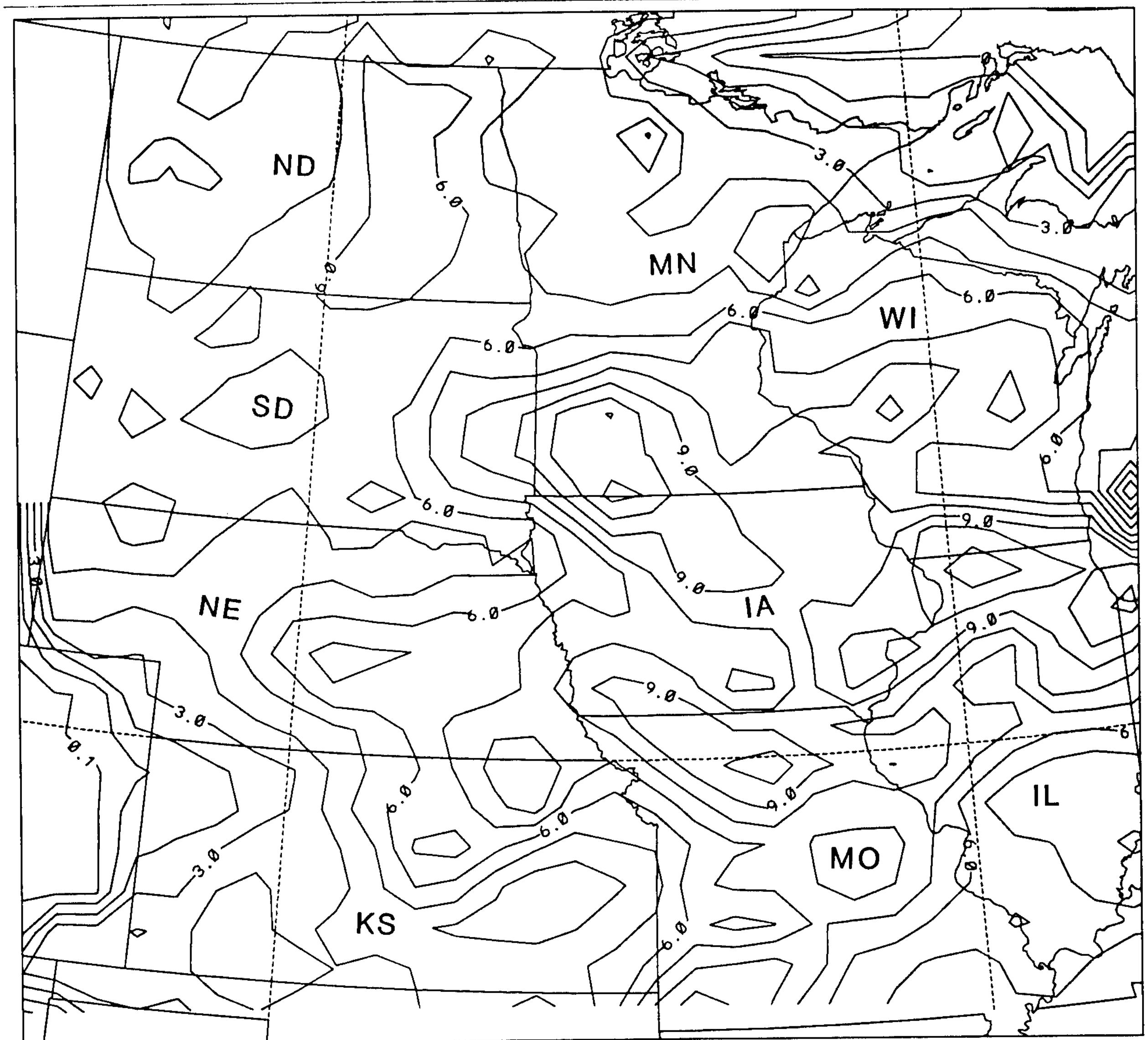
a small area. A maximum rainfall of 24 inches in a period of six hours was reported. For small areas and short durations, storm precipitation in 1935 exceeds that of the 1951 storm. For an area of 2,000 square miles and duration of 24 hours, the maximum average rainfall in May 1935 was 5.5 inches, compared with 6.2 inches for the July 1951 storm.

The storm of May 6-11, 1943, is of particular interest because of the heavy precipitation that occurred over a large area. Rainfall from this storm extended from Oklahoma and Arkansas northeastward across southeastern Kansas and into Missouri, Illinois, and Indiana. A total of more than 200,000 square miles is encompassed by the 3-inch isohyet for the 1943 storm compared with 57,000 square miles for the July 1951 storm. The storm center was at Warner, Okla., where 25 inches of precipitation was reported for the storm period of 192 hours. For a 72-hour duration, this storm had approximately 15 percent greater rainfall depth than the July 1951 storm.



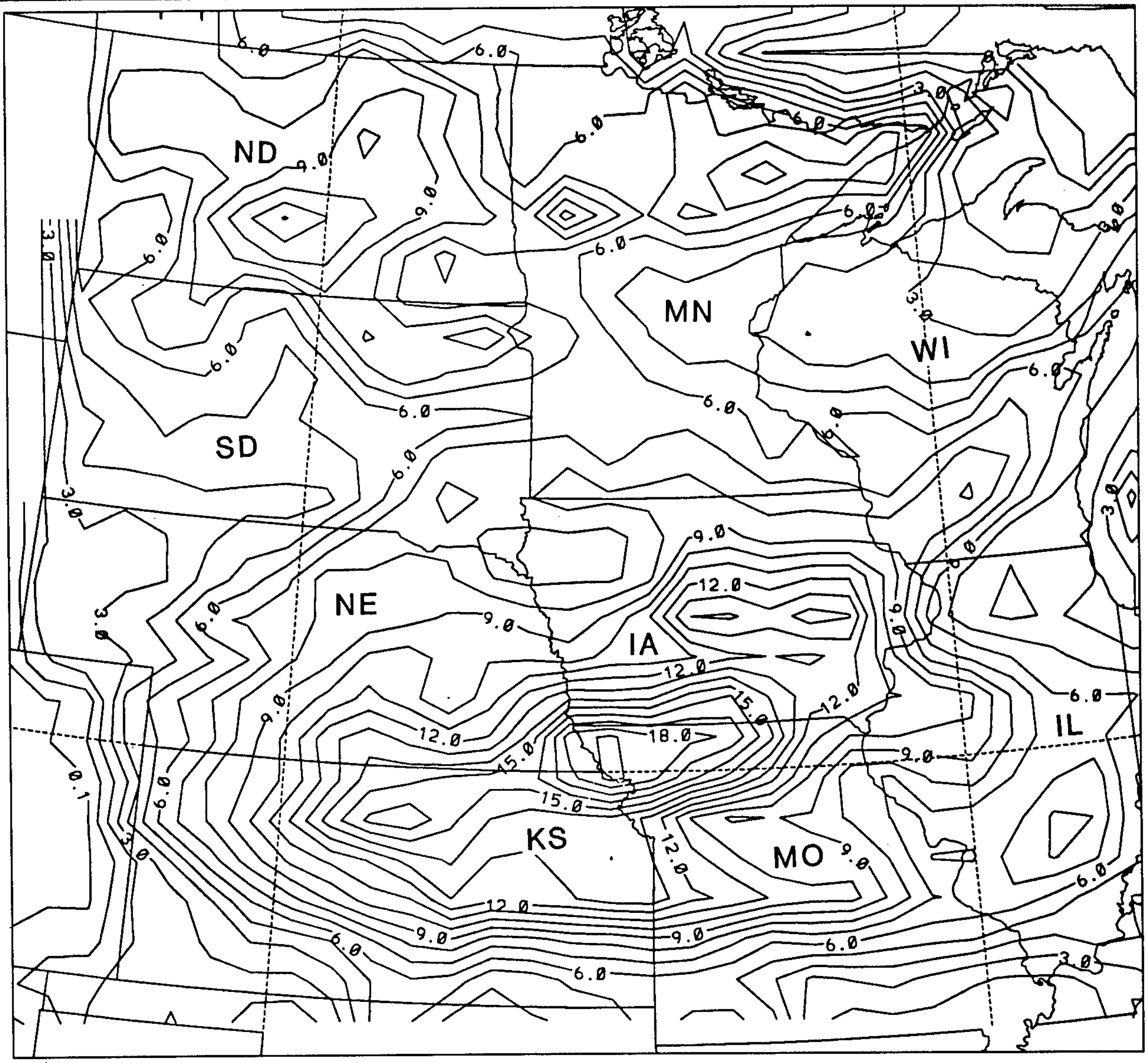
(Source: IL State Water Survey)

Figure 5. May 1993—Rainfall (Inches)



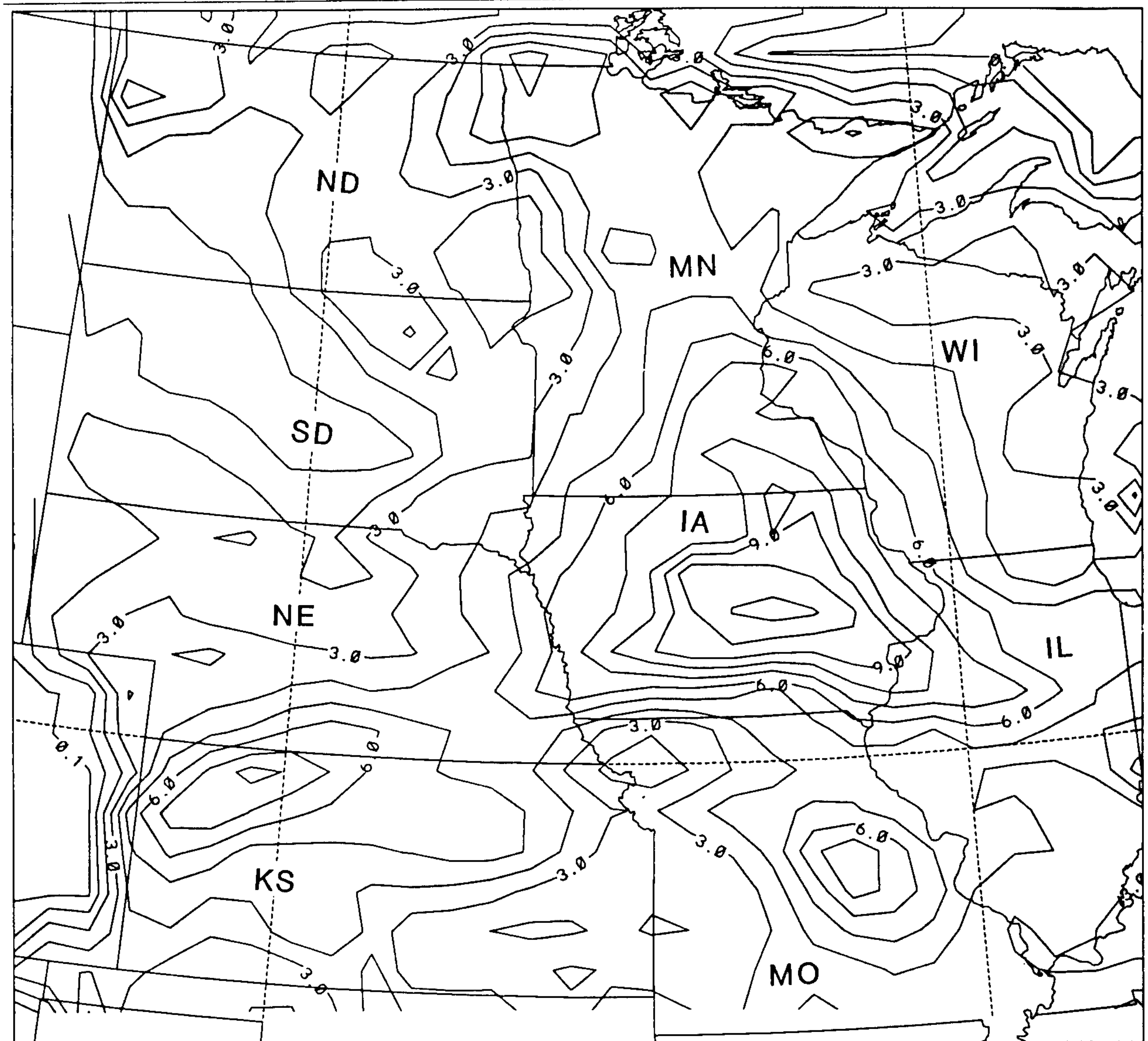
(Source: IL State Water Survey)

Figure 6. June 1993—Rainfall (Inches)



(Source: IL State Water Survey)

Figure 7. July 1993—Rainfall (Inches)



(Source: IL State Water Survey)

Figure 8. August 1993—Rainfall (Inches)

Section III
General Hydrology and Hydraulics

Antecedent Conditions

A number of conditions can affect runoff in a river basin and result in major flooding. The four most significant conditions relevant to the floods of the summer of 1993 in the upper Mississippi and lower Missouri river basins were base flow, snow cover, soil moisture, and antecedent precipitation.

Base Flow

Along the Mississippi River from Hastings, Minn.; to Guttenberg, Iowa, flows displayed an average fluctuation consistent with the alternating patterns of colder and milder weather. This trend was also generally observed along the Mississippi River tributaries in western and central Wisconsin, except that base flows tended to remain somewhat above average for most of the season. On the Minnesota River, base flows were well above the monthly averages throughout the winter.

From Lock and Dam 11 in Guttenberg, Iowa, to Lock and Dam 22 in Saverton, Mo., streamflows were unusually high during the winter and spring of 1992-1993. River flows at Lock and Dam 11 were between 30,000 and 40,000 cubic feet per second during the months of January and February, compared with average flows of 25,000 cfs. Lock and Dam 22 recorded river flows greater than 60,000 cfs for most of the same time period, compared with average flows of 35,000 cfs.

The Rock and Illinois rivers, two major tributaries to the Mississippi River from the Illinois side, experienced similar unseasonably high base flows throughout the winter months.

This indicates that high base flow was a moderate contributing factor to the summer floods on the tributaries, and was a highly significant contributing factor to the summer floods.

Snow Cover

Although not record breaking, the snow cover in the upper Mississippi River basin at the beginning of the 1993 spring season was somewhat greater than normal, particularly in southern areas. Across southern Minnesota and western and central Wisconsin, snow depths at the end of February 1993 were generally in the 9- to 18-inch range with water equivalents in the 2- to 4- inch range. Frost penetration ranged from 14 inches at Lamberton to 34 inches at Morris in Minnesota, with a similar range in western and central Wisconsin. These values are not abnormal, and suggest that snow and soil conditions at the end of winter 1992-1993 were not significant contributing factors to the floods of the summer 1993. However, melting snow did combine with above-normal spring rains and below-normal spring temperatures to adversely impact soil moisture conditions.

Soil Moisture

Soil moisture across Minnesota, Wisconsin, and Iowa in the spring of 1993 was extremely high, making this a significant contributing factor to the floods in the summer of 1993.

The high soil moisture meant that a large percentage of new precipitation had nowhere to go but directly into runoff.

Precipitation

Precipitation patterns over Minnesota, Wisconsin, and Iowa since 1992 were a significant contributing factor to the floods of 1993.

Precipitation in November 1992 was higher than average in all of the Midwest. Statewide precipitation records in Iowa, Minnesota, and Wisconsin were the greatest of any November since 1895. Illinois and Missouri were the second wettest. The period of January through August 1993 broke many precipitation records.

The first three months of 1993 were generally recorded as near normal precipitation.

The spring of 1993 was characterized by two highly significant climatic factors. These were above-normal precipitation and below-normal temperatures.

Above normal precipitation fell in most areas in April and throughout the region in May. Nearly twice the normal precipitation fell in May. This

Nutwood Levee break on the Illinois River.

above normal precipitation was accompanied by significantly below normal temperatures. Mean April temperature ranged from 3 to 4 degrees below normal across the entire area, with isolated stations reporting monthly averages about 7 degrees below normal. Monthly average temperatures for May were colder than normal by 1.5 to 2.5 degrees Celsius.

Rainfall for the month of May varied from 4 inches in Missouri, Iowa, Minnesota, and southern Illinois to more than 6 inches in the western half of Iowa and northwestern Missouri.

This combination of precipitation and temperature had several effects. The above normal precipitation, combined with the melted winter snow pack, left soils very close to saturation. The cooler temperatures inhibited evapotranspiration, further promoting saturated soil conditions and ponding in fields. Both of these conditions delayed planting and inhibited crop-root growth, which in turn contributed further to excessive runoff.

Description of Flooding

The Great Flood of 1993 was unique in its areal extent as well as its duration. It encompassed several months of relatively heavy rainfall that occurred at a time when the ambient conditions already posed a greater probability for flooding. Along the Mississippi River, many of the federal and non-federal levees either overtopped or were breached as a result of the record-breaking stages.

The flooding on the Mississippi River was the most devastating of any flood in the history of the United States in terms of property damage, disrupted businesses, and personal trauma. Millions of acres of farmland were under water for weeks during the growing season. Damaged highways and roads disrupted overland transportation throughout the flooded region. The river was closed to navigation for several weeks. The banks and channels of the Mississippi River were severely eroded in many reaches. In addition to the erosion of the river, erosion of valuable topsoil was a major problem. The extent and duration of the flooding overtopped numerous levees.

The flood affected a large portion of the Midwestern United States, crossing boundaries of several Corps of Engineers districts, including: St. Paul, Rock Island, Omaha, Kansas City, and St. Louis. Each of these district's areas experienced some degree of flooding during the spring and summer of 1993.

Flood effects along the main stem of the Mississippi River were generally confined to near-bank areas and channel infrastructure from St. Paul, Minn., to Guttenberg, Iowa. There was no significant flooding upstream of Lock and Dam No. 1 in Minneapolis, Minn.

Every gaging station on the Mississippi River below Lock and Dam No. 15 to Thebes, Ill., experienced a new flood of record. Above Lock and Dam 15, the 1993 flood was surpassed by only one other event.

Flood conditions on the Mississippi River differed above and below the confluence of the Ohio River. At Thebes, Ill., 46 miles upstream from the confluence, severe flooding occurred on the Mississippi. Downstream from the confluence, flooding on the Mississippi River was not severe, because of less-than-average discharge contributed by the Ohio River and a substantially larger channel capacity in this reach of the Mississippi River. The discharge of the Ohio River was less than average during July and August as a result of generally dry conditions and low reservoir outflows throughout the Ohio River.

The wet spring of 1993 resulted in the Missouri River rising above flood stage in early May and navigation being suspended from river mile 197.0 to 354.0. By May 16 the river was reopened to navigation. This relatively minor event set the stage for a series of events that would result in record flows and stages on the Missouri River and record pool levels at several lake projects during the months of July and August.

Hydrologic and hydraulic effects of excessive runoff during the summer of 1993 resulted in severe and widespread flooding throughout the lower Missouri River basin in Missouri, central and east Kansas, southeast Nebraska, and south central and southwest Iowa. Several intense storms in July, combined with wet antecedent conditions, were the main causes of the severe flooding conditions. Record flooding inundated large areas—residential, industrial, and agricultural. The extent and duration of flooding caused levees on the Missouri River to fail or be overtopped. The Missouri River was closed to navigation for 49 days, from July 2 to Aug. 20.

Even after the record-setting flood had passed out of the Missouri River basin, during August and September, continued rainfall caused recurrences of flooding in localized areas. Rainfall also continued to interfere with the task of post-flood cleanup and rehabilitation.

Comparison with Previous Floods

Streamflow records on the main stem of the Mississippi River date back to the 1860s when the first gage began operation at St. Louis, Mo.

Flood of 1844. The winter of 1843-1844 experienced tremendous snowstorms throughout the Midwest. The winter broke up early in May, but the weather continued cool and the spring was characterized by the most severe rainstorms ever known in the northwest. By the first of May, the river was full to overflowing. As rains fell, the river continued to rise from May 10-20, reaching the doors of the stores on Front Street north of Pine in St. Louis and extending to the Pap House in east St. Louis on the Illinois side, a distance of 2.5 miles. The river started to recede on May 23 and was within its banks on June 7. But the flood from the Missouri was yet to come. In addition, from June 3-10, there was a continued succession of very heavy rainstorms generally throughout the northwest, and all the rivers above St. Louis were reported to be rising.

The Mississippi River again began to rise at

Flooding on the Minnesota River at St. Peter, Minn., State Highway 22 Bridge.

St. Louis on June 8. The Missouri, upper Mississippi, and Illinois rivers and their tributaries were overflowing their banks and rising rapidly, spreading destruction and consternation among the inhabitants of the bottoms, where losses were very great. The river continued rising from June 8 until the peak was reached June 27, when a stage equivalent to 41.32 feet on the present Market Street gage was recorded. In the early 1900s, it was estimated that the peak flow amounted to 1,300,000 cfs at St. Louis. Recent studies indicate that the peak discharge of the flood may have been overestimated by as much as 30 percent.

Flood of 1927. The Flood of 1927 on the Mississippi River from Grafton, Ill., southward was unusually high. The river crested at St. Louis on April 26 at 36.1 feet and remained above flood stage from April 13 to May 1. The maximum discharge at St. Louis was 889,000 cfs. Although this flow is overestimated, the 1927 flood was the flood of record for the lower Mississippi River Valley. The Flood of 1927 affected an area the size of Indiana and forced 600,000 people from their homes. At some locations, flood waters stretched 80 miles wide in the lower valley. The damage estimated in 1993 dollars was $4.4 billion, a fraction of the estimated damage from the current flood, due in part because there was much less development along the river at that time.

Flood of 1965. The April 1965 flood was the flood of record for the 700-mile reach of the Mississippi River between Royalton, Minn., 100 miles upstream of Minneapolis, to just below Hannibal, Mo. The flood was caused by (1) an early fall freeze that lowered the frost depth deeper before the snow cover began and (2) a February thaw with rain in southern Minnesota and northern Iowa under conditions of nearly impermeable surface ground conditions. A third contributing factor was the March snowfall (300 percent above normal) in east-central Minnesota, together with a late period of cold weather in March and early April that prevented the gradual runoff of the snowpack. The 1965 flood exceeded prior records by several feet at numerous gaging stations in the basin and caused $225 million damage to public and private properties. Of this, $173 million damage occurred along the main stem of the Mississippi River. Flood-control projects, emergency actions and evacuations, based on National Weather Service forecasts prevented, approximately $300 million in damage.

Flood of 1973. Periods of snow and severe cold temperatures occurring during December 1972 and early January 1973 alternated with short periods of warmer weather accompanied by rainfall. Unseasonably warm weather during the second half of January and all of February caused considerable surface thawing and melting of the snow cover. Flooding was generally caused by torrential rains falling on saturated soil and rivers with extremely high base streamflows. Flooding on the Mississippi River consisted of three distinct crests. In each case, the crests of the tributary stream rises coincided with the crest of the Mississippi River as it progressed downstream. This synchronization of tributary inflow augmented the main-stem flows sufficiently to cause the second crest to surpass all previous stages below Burlington, Iowa. The peak flow was 414,000 cfs on April 25. In 1973, the crest at Hannibal, Mo., and Quincy, Ill., was 4 feet higher than in 1965. The flood displaced 10,000 people and inundated 180,000 acres. The river was above flood stage at Hannibal for 106 days. Also, for the first time, Corps flood-control measures prevented more damage than occurred. In 1973, the St. Louis gage was more than 40 feet for eight days. Figure 9 shows a comparison between the hydrographs of the 1973 and 1993 floods at St. Louis. Table 1 lists the historic stages and the flows at St. Louis for the ten highest historic floods.

Table 1
Ten Highest Historic Flows And Associated Stages At St. Louis

Flood Date	Flow (cfs)	Stage (ft)
August 1993	1,070,000	49.6
June 1844	1,300,000*	41.3
June 1903	1,019,000*	38.0
April 1927	889,000	36.1
April 1973	852,000	43.3
April 1944	844,000	39.1
May 1943	840,000	38.9
July 1947	783,000	40.3
July 1951	782,000	40.3
October 1986	728,000	39.1

*Estimated (not measured).

Flow Frequency

The 1993 flood at Davenport, Iowa, was estimated as a 100-year event; at Burlington, Iowa, it was a 200-year event; and at Quincy, Ill., and Louisiana, Mo., the flood was estimated to be a 500-year event. Further downstream, at St. Louis, Mo., it was a 150- to 200-year event, and a 100-year event at Chester, Ill. At Cape Girardeau, Mo., (above the junction with the Ohio River) the return period is estimated to be between a 50- to 100-year event.

A discharge-frequency study for the Missouri River was made by the Corps of Engineers in 1962. The 100-year and 500-year peak discharge estimates for stream gaging stations on the Missouri River are shown in the first two columns of Table 2. These estimates reflect the operation of the existing Missouri River system of lakes and reservoirs. For comparison purposes, the peak discharges for the 1993 flood are shown in the third column of this table. This information suggests that the frequency of the 1993 flood is approximately a 500-year event. However, in order to make a reasonably reliable estimate of the frequency of the 1993 flood, an updated analysis of the 1962 study would be required. A re-analysis would need to include the 1993 peak discharges and all other annual peak discharges that have occurred since the study was made. A thorough and complete discharge-frequency reevaluation for the Mississippi and Missouri rivers is beyond the scope of this report.

A comparison of data concerning 1993 unregulated peak discharges with 1844 estimated peak discharges is presented in the fourth and fifth columns of Table 2. The 1844 peak discharge at Hermann is greater than the 1993 unregulated peak discharge and 1993 unregulated peak discharges at Kansas City and Boonville are greater than the 1844 peak discharges.

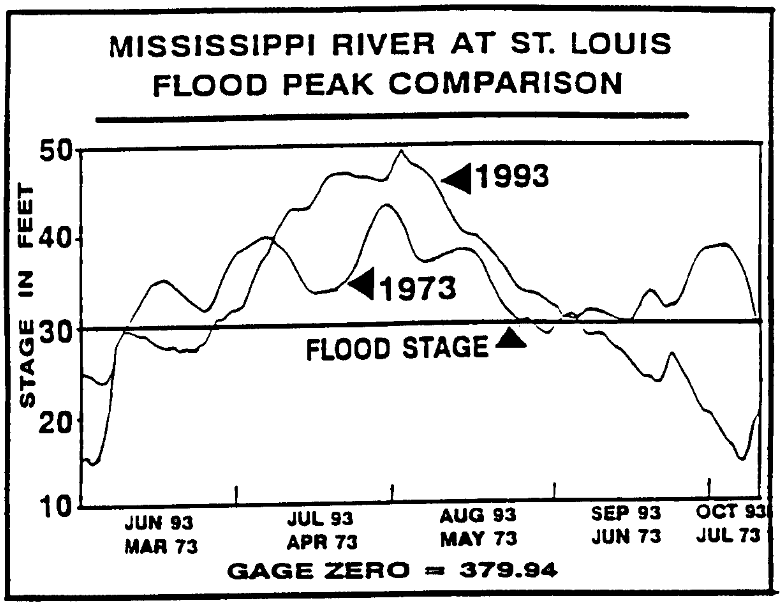


Figure 9. Mississippi River at St. Louis flood peak comparison.

Typical cross sections from pools 11 through 22 on the Mississippi River were selected from 1992 and 1993 soundings. These cross sections were compared to determine whether deposition or scour had occurred as a result of the flooding. Based on the 26 selected cross sections, it was determined that 13 of the 26 sections showed sediment deposition. Only four of the cross sections showed degradation across the entire channel. The remaining nine sections either had little or no change or had equal amounts of degradation and aggregation across the section. In pool 11, up to 5 feet of scour occurred. At pool 18, as much as 9 feet of sediment was deposited. These two sections show the extreme cases of erosion and deposition in the cross sections that were evaluated, however, they indicate that significant changes in the channel occurred in one year as a result of the extreme flows.

Where levees overtopped, considerable scour and deposition occurred. Scour holes 50 to 70 feet deep, up to a half-mile wide and extending more than 1,000 feet landward occurred at some locations. Deposition of sediments covered farmland with many feet of sand.

The significance of depth changes on the Mississippi and Missouri rivers will not be known until more analysis is done for other time periods.

A more comprehensive study of 1993 flood changes to the Mississippi and Missouri river channels is beyond the scope of this report.

General Description of Channel Changes

Preliminary studies of the Mississippi and Missouri rivers have been done to determine what, if any, changes occurred to the channels due to the 1993 flood.

Evidence for the classic sediment transport theory that during a flood, erosion occurs at the bends and deposition occurs at the crossings was found in parts of the reaches, but other factors also affect sediment transport. Most important among these factors is how divided the flow is in a given reach, that is, how much flow is leaving the navigation channel and entering backwater areas.

The potential sources of sediment include tributaries, upstream channel erosion, erosion from wingdam fields, and bank erosion.

A preliminary study of Mississippi River pools 2, 5, 5a, 7, and 8 showed that in pools 2, 5, 7, and 8, the summer flood caused net deposition. In pool 5a, net erosion occurred.

Effects of Levees and Reservoirs on the Flood

The effects of flood-control structures are questioned every time a large flood occurs, and the Great Flood of 1993 proved no exception. Almost every day, the news media showed pictures of levees overtopping and rampaging flood waters entering protected areas. Essentially, little media coverage was seen of flood- control projects successfully preventing flooding. The general impression on the part of the general public seemed summed up in such questions as why is a flood occurring with all the flood-control structures that exist? What has gone wrong? With this perception of flood-control structure failure, why not go in another direction, like wetlands? This impression was generally conveyed by the media as fostered by some environmental interests.

Contrary to popular belief, however, structural efforts—involving levees, floodwalls, and reservoirs—performed in an outstanding fashion during the Flood of 1993. All structures that were designed for an event of this magnitude prevented flooding to the areas protected by the structures. In fact, many levees designed for events less severe than 1993 also stood up to this event due to heroic flood-fight measures. If not for federal flood-control structures, an additional $19 billion in damage would have been experienced, more than double the actual flood damage.

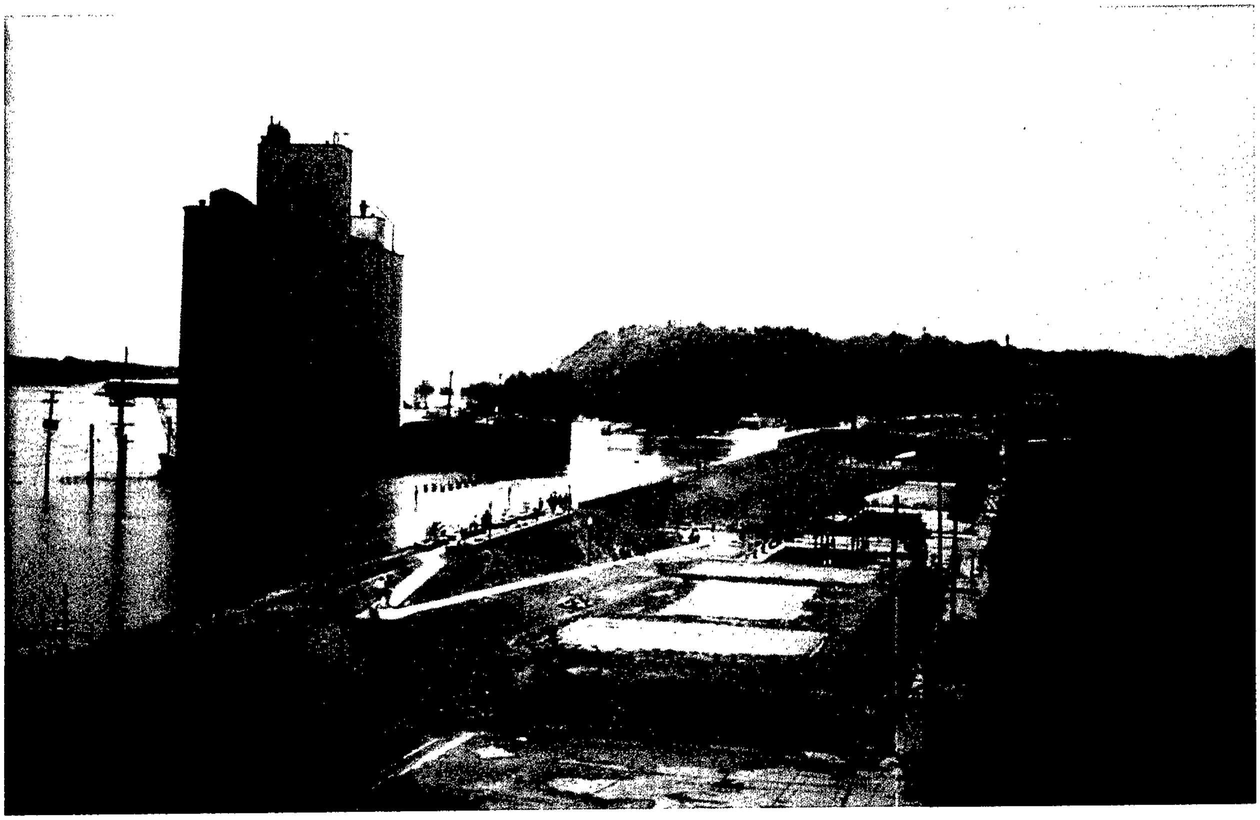
Another way of viewing the success of flood-reduction structures is to compare the costs of the structures to the benefits received. The total expenditures on flood-control structures throughout the history of the United States is estimated at $25 to $30 billion. Just in the past ten years, flood damage has been reduced an estimated $170 billion. In addition, the case could be made that the entire flood-reduction system has paid for itself once every 18 months, based on the last decade of flooding.

Flood control structures exist because the public has wanted them. All structures are built due to petitions of local residents to their Congressional representatives for relief from flooding. Not all projects requested are built, however. For the Corps of Engineers to construct a flood control measure, the project requires that it be engineeringly safe, economically viable, and

Table 2

Data on Frequency of Peak Discharges on the Missouri River

Stream Gage Station	1962 Study		1993 Flood		1844 Flood
	100-Year Peak Discharge (cfs)	500-Year Peak Discharge (cfs)	Actual Peak Discharge (cfs)	Unregulated Peak Discharge (cfs)	Estimated Peak Discharge (cfs)
Omaha	190,000	250,000	115,000	185,000	n/a
Nebraska City	220,000	265,000	196,000	270,000	n/a
Rulo	241,000	290,100	307,000	386,000	n/a
St. Joseph	270,000	330,000	335,000	461,000	n/a
Kansas City	425,000	540,000	541,000	713,000	625,000
Waverly	445,000	560,000	633,000	700,000	n/a
Boonville	550,000	700,000	755,000	738,000	710,000
Hermann	620,000	820,000	750,000	852,000	892,000



The Hannibal, Mo., Flood Control Project protected the city from Mississippi River flooding.

environmentally sound. The level of flood protection also varies widely depending on one's location. The lower Mississippi River, below the mouth of the Ohio River, has a very high level of flood protection. An extensive system of levees, floodways, channel maintenance, reservoirs, and tributary improvements was prompted after the disastrous Flood of 1927 occurred. In contrast, the upper Mississippi and Missouri rivers have a far less extensive system. In these two basins, most urban areas have a high level of protection offered by levees, floodwalls, and reservoirs. However, non-urban areas (most of the floodplain of the two rivers) have a much lower protection level—far less than that associated with the 1993 event. Most of these areas are partially protected by non-federal levees that generally offer protection only to frequently occurring flood events, such as a 20- or 50-year flood. Consequently, it was not surprising to see so many agricultural levees overtopped in 1993. Levees are designed to prevent flooding up to the design flood elevation, usually 2 to 3 feet below the top of the levee. The Flood of 1993 was several feet above the top of many levees; however, that did not mean that the levee "failed." A "failure" means that the levee broke before its design was exceeded. In only one instance during the Flood of 1993 did this occur. In hundreds of other cases, the levees did their job, at least through the occurrence of design river elevations and usually to the top of the levee.

By protecting the areas behind the levees, flood flows are partially constrained by levees and forced to flow through a narrower cross section. This constriction causes flood levels to be higher for a specified distance upstream, until these higher levels eventually dampen out. These increases are identified during engineering studies and minimized as much as practical. For large rivers like the Missouri and Mississippi, the induced effects of levees can be largely offset by upstream flood control reservoirs. The effects of levees vary, depending on the height of the levee and its nearness to the river. Non-federal levees typically cause smaller effects than federal levees because they are usually much lower. System-wide effects of induced flooding are not defined at every possible location; however, these effects are generally estimated to range from a few inches to 2 feet for most floods, with maximum effects of about 4 feet at constricted locations like St. Louis for the Flood of 1993. These figures could be different (probably smaller) at other locations. As mentioned previously, these induced flooding figures dampen out as one progresses upstream. When a densely populated urban area like the floodplain at St. Louis requires protection, some induced flooding is acceptable to prevent the extensive flood damage (costing several billion dollars) that would occur without the urban levee and floodwall system. These increases at St. Louis have been found to be fully offset by reductions in the flood discharge attributable to upstream reservoirs.

There are 76 flood-control reservoirs in the upper Mississippi and Missouri river basins upstream of the mouth of the Ohio River. Most of the reservoirs, and the greatest potential to reduce flooding, are in the Missouri River basin. These 76 structures range from the massive dams and reservoirs on the main-stem Missouri River in Montana and the Dakotas to small headwater reservoirs on tributaries of both rivers. Due to the reservoirs, some reduction to Mississippi River and Missouri River flood flows occurs for every flood. During the last 20 years, flood stages have been reduced at St. Louis from 2 to 7 feet, depending on the flood event. During the Flood of 1993, reservoirs reduced the peak stage at St. Louis by at least 4 feet, fully offsetting the effects of levees. Without the reservoirs, most of the urban levees at St. Louis would have been overtopped. Reservoirs had significant impacts on the Missouri River, reducing the peak stage at Sioux City, Iowa, by 6 feet; at Omaha, Neb. by 5 to 8 feet; at Kansas City, Mo. by 3 to 4 feet; and at Hermann, Mo. by 3 feet.

Reservoir effects on the Mississippi River upstream of the mouth of the Missouri were lower; generally less than 1 foot upstream of Louisiana, Mo., and 1 to 2 feet downstream of Louisiana.

Floods can never be 100 percent controlled. Flood-reduction structures are designed to minimize the damage caused by floods. The successes of federal projects were well demonstrated during the Flood of 1993. The federal levees, floodwalls, and reservoirs constituted a great success story; however, it was a story that received far less media coverage than it deserved.

Table 3
Summary of Peak Stages and Discharges During 1993 Flood at Select U.S. Geological Survey Stations

Site No.	Station No.	Station name	Drainage area (sq. mi.)	Peak stage (ft)	Peak discharge (cfs)	Date
1	05290000	Little Minnesota River near Peever, S. D.	447	13.58	8,900	7/25
2	05292000	Minnesota River at Ortonville, Minn.	1,160	9.99	2,950	7/28
3	05311000	Minnesota River at Montevideo, Minn.	6,180	16.47	11,500	8/04
4	05320000	Blue Earth River near Rapidan, Minn.	2,430	13.32	20,300	6/20
5	05320500	Le Sueur River near Rapidan, Minn.	1,100	13.32	11,500	6/21
6	05325000	Minnesota River at Mankato, Minn.	14,900	30.13	75,800	6/21
7	05330000	Minnesota River near Jordon, Minn.	16,200	33.52	92,200	6/24
8	05331000	Mississippi River at St. Paul, Minn.	36,800	19.13	104,000	6/26
9	05369500	Chippewa River at Durand, Wis.	9,010	15.76	90,100	6/23
10	05382000	Black River near Galesville, Wis.	2,080	16.64	64,000	6/21
11	05398000	Wisconsin River at Rothschild, Wis.	4,020	27.48	44,400	6/21
12	05404000	Wisconsin River near Wisconsin Dells, Wis.	8,090	18.16	59,100	6/24
13	05407000	Wisconsin River at Muscoda, Wis.	10,400	10.34	59,600	6/26
14	05420500	Mississippi River at Clinton, Iowa	85,600	22.98	239,000	7/07
15	05432500	Pecatonica River at Darlington, Wis.	273	18.22	12,400	7/06
16	05433000	East Branch Pecatonica River near Blanchardville, Wis.	221	16.54	5,660	7/06
17	05451500	Iowa River at Marshalltown, Iowa	1,564	20.77	20,400	8/17
18	05453100	Iowa River at Marengo, Iowa	2,794	20.31	38,000	7/19
19	05454300	Clear Creek near Coralville, Iowa	98	14.74	6,760	7/06

Site No.	Station No.	Station name	Drainage area (sq. mi.)	Peak stage (ft)	Peak discharge (cfs)	Date
20	05455700	Iowa River at Lone Tree, Iowa	4,293	22.94	57,100	7/07
21	05465000	Cedar River near Conesville, Iowa	7,785	16.74	66,500	7/07
22	05465500	Iowa River at Wapello, Iowa	12,499	29.53	111,000	7/08
23	05470000	South Skunk River near Ames, Iowa	315	14.23	11,200	8/16
24	05470500	Squaw Creek at Ames, Iowa	204	18.54	24,300	7/09
25	05471000	South Skunk River below Squaw Creek near Ames, Iowa	556	25.53	26,500	7/09
26	05471500	South Skunk River near Oskaloosa, Iowa	1,635	24.78	20,700	7/15
27	05472500	North Skunk River near Sigourney, Iowa	730	24.68	17,500	7/06
28	05474000	Skunk River at Augusta, Iowa	4,303	23.70	46,600	7/10
29	05474500	Mississippi River at Keokuk, Iowa	119,000	27.58	446,000	7/10
30	05476000	Des Moines River at Jackson, Minn.	1,220	16.67	8,250	7/07
31	05476750	Des Moines River at Humboldt, Iowa	2,256	15.22	19,000	7/13
32	05480500	Des Moines River at Fort Dodge, Iowa	4,190	15.81	31,200	4/01
33	05481300	Des Moines River near Stratford, Iowa	5,452	25.68	42,300	4/02
34	05481650	Des Moines River near Saylorville, Iowa	5,841	24.22	45,700	7/21
35	05482500	North Raccoon River near Jefferson, Iowa	1,619	19.20	16,900	7/10
36	05484500	Raccoon River at Van Meter, Iowa	3,441	26.34	70,100	7/10
37	05485500	Des Moines River below Raccoon River at Des Moines, Iowa	9,879	34.29	116,000	7/11
38	05487980	White Breast Creek near Dallas, Iowa	342	30.20	25,500	7/06
39	05488500	Des Moines River near Tracy, Iowa	12,479	24.16	109,000	7/12
40	05489000	Cedar Creek near Bussey, Iowa	374	28.53	36,100	7/05

Site No.	Station No.	Station name	Drainage area (sq. mi.)	Peak stage (ft)	Peak discharge (cfs)	Date
41	05489500	Des Moines River at Ottumwa, Iowa	13,374	22.15	112,000	7/12
42	05490500	Des Moines River at Keosauqua, Iowa	14,038	32.66	109,000	7/13
43	05569500	Spoon River at London Mills, Ill.	1,072	26.42	22,600	7/25
44	05570000	Spoon River at Seville, Ill.	1,636	33.10	34,700	7/26
45	05586100	Illinois River at Valley City, Ill.	26,742	25.95*	92,400	8/01
46	06341800	Painted Woods Creek near Wilton, N. D.	427	8.13	1,580	7/23
47	06347500	Big Muddy Creek near Almont, N. D.	456	30.94	8,680	7/23
48	06348000	Heart River near Lark, N. D.	2,750	16.85	12,100	7/23
49	06467600	James River near Manfred, N. D.	253	9.40	2,700	7/23
50	06468170	James River near Grace City, N. D.	1,060	3.49	3,520	7/28
51	06470000	James River at Jamestown, N. D.	2,820	13.58	1,300	7/16
52	06477150	Rock Creek near Fulton, S. D.	240	14.34	1,880	7/06
53	06478500	James River near Scotland, S. D.	20,653	19.76	19,600	7/06
54	06478513	James River near Yankton, S. D.	20,942	21.15	15,800	7/08
55	06480000	Big Sioux River near Brookings, S. D.	3,898	13.50	13,300	7/04
56	06480400	Spring Creek near Flandreau, S. D.	63	16.84	4,480	7/03
57	06481000	Big Sioux River near Dell Rapids, S. D.	4,483	15.56	16,400	7/04
58	06483500	Rock River near Rock Valley, Iowa	1,592	19.97	28,500	7/12
59	06605850	Little Sioux River at Linn Grove, Iowa	1,548	20.63	16,100	7/02
60	06606600	Little Sioux River at Correctionville, Iowa	2,500	23.82	122,600	7/18
61	06799350	Elkhorn River at West Point, Neb.	5,100	14.02	28,800	7/09
62	06800500	Elkhorn River at Waterloo, Neb.	6,900	15.76	33,600	7/11

Site No.	Station No.	Station name	Drainage area (sq. mi.)	Peak stage (ft)	Peak discharge (cfs)	Date
63	06801000	Platte River at Ashland, Neb.	84,200	21.45	114,000	7/25
64	06805500	Platte River at Louisville, Neb.	85,800	11.90	160,000	7/25
65	06807000	Missouri River at Nebraska City, Neb.	410,000	27.19	196,000	7/13
66	06808500	West Nishnabotna River at Randolph, Iowa	1,326	23.60	22,100	7/23
67	06810000	Nishnabotna River above Hamburg, Iowa	2,806	30.56	37,700	7/25
68	06813500	Missouri River at Rulo, Neb.	414,900	25.37	307,000	7/24
69	06818000	Missouri River at St. Joseph, Mo.	420,300	32.07	335,000	7/26
70	06853020	Republican River at Guide Rock, Neb.	22,090	15.47	9,860	7/19
71	06879100	Kansas River at Fort Riley, Kan.	44,870	27.93	87,600	7/26
72	06887500	Kansas River at Wamego, Kan.	55,280	27.33	199,000	7/26
73	06889000	Kansas River at Topeka, Kan.	56,720	34.90	170,000	7/25
74	06891000	Kansas River at LeCompton, Kan.	58,460	24.65	190,000	7/27
75	06893000	Missouri River at Kansas City, Mo.	485,200	48.87	541,000	7/27
76	06895500	Missouri River at Waverly, Mo.	487,200	31.15	600,000	7/28
77	06897500	Grand River near Gallatin, Mo.	2,250	41.50	89,800	7/07
78	06902000	Grand River near Sumner, Mo.	6,880	42.52*	150,000	7/26
79	06909000	Missouri River at Boonville, Mo.	501,700	37.10	755,000	7/29
80	06934500	Missouri River at Hermann, Mo.	524,200	36.97	750,000	7/31
81	07010000	Mississippi River at St. Louis, Mo.	697,000	49.58	1,070,000	8/01
82	07020500	Mississippi River at Chester, Ill.	708,600	49.74	1,000,000	8/07
83	07022000	Mississippi River at Thebes, Ill.	713,200	45.51	996,000	8/07

*Peak stage/peak discharge occurred on different dates.

Tuttle Creek Lake spillway (Kansas River) after the flood.

Section IV
General USACE Activities

Reservoir Regulation

Upper Mississippi River Basin

In the North Central Division, there are 14 reservoirs, 25 locks and dams on the Mississippi River, and eight locks and dams on the Illinois Waterway that regulate the 9-foot navigation pools. Of the 14 reservoirs, only three had significant involvement in the Flood of 1993. The three, all in the state of Iowa, were Coralville Reservoir on the Iowa River and Saylorville and Red Rock reservoirs on the Des Moines River. These two systems are regulated by Control Index Stations (CIS) on the Mississippi River. For the Coralville Reservoir, the CIS is at Muscatine, Iowa, at river mile (r.m.) 455.2; for the Saylorville/Red Rock reservoirs there is a CIS at Burlington, Iowa, (r.m. 403.1) and at Quincy, Ill., (r.m. 327.0).

The impact of these two systems downstream of Quincy is quickly moderated by tributary inflows from the Illinois River, which covers approximately 18 percent of the total upper Mississippi River basin.

During the April 1973 flood, the operation of the Coralville and Saylorville/Red Rock reservoirs reduced the stages at Quincy, Ill., and Hannibal, Mo., (r.m. 309.9) by 1.2 feet and 2.0 feet, respectively. During the Flood of 1993, the reported stage reduction at these same stations was 0.9 foot and 0.2 foot respectively. The 1993 reductions were smaller because the reservoirs were already at or above flood pool during the lengthy flood event.

During the Flood of 1993, Coralville Reservoir was operated in accordance with the prescribed regulation plan (see Appendix B) until July 11. On that date, the lake reached a level 0.9 foot above the top of the flood-control pool. Downstream, in Iowa City, the University of Iowa and city officials were frantically trying to protect their water-treatment plants. The Corps deviated from the regulation plan to operate the release rates outside the specified regulation curves. On Aug. 2, when the pool level fell below the emergency spillway level of 712 feet National Geodetic Vertical Datum, the operation resumed on the prescribed regulation schedule. The peak pool elevation reached 716.7 feet NGVD, and the peak outflow was 24,600 cubic feet per second (cfs).

Saylorville Lake was also operated through July 11 according to its regulation plan. On that date, the lake level was 0.4 foot above the top of the flood-control pool. The Des Moines, Iowa, water-works levees had failed earlier that day because record flows from the Raccoon River tributary. The reservoir releases, combined with record Beaver Creek tributary flows, were about to overtop the Des Moines River levees. The regulation plan was deviated from to decrease the outflow rate by 6,000 cfs, which allowed for a successful defense of the downstream levees. The reservoir finally reached a peak elevation of 892.0 feet NGVD and a maximum outflow of 44,500 cfs.

About 71 miles downstream of Saylorville Lake is Lake Red Rock where releases followed the prescribed regulation plan (see Appendix B) until July 5. On that day, the lake level was 0.3 foot below the top of the flood-control pool. Downstream, at Ottumwa and Eddyville, Iowa, flood-fight efforts were ongoing to save the water treatment plant, and the Corps reduced the outflow. The reservoir pool peaked at elevation 782.7 feet NGVD on July 13 with a peak outflow of 104,000 cfs.

Mark Twain Lake is on Salt River, a tributary to the Mississippi River below Hannibal, Mo., and downstream of Lock and Dam 22 (r.m. 284.2). The reservoir releases were restricted to 2,000 cubic feet per second while the Mississippi River was at flood stage. Because of the restricted release rate, 50 percent of the flood-control storage was used in April 1993.

Missouri River and Tributaries

The Missouri River has 35 Corps or Bureau of Reclamation reservoir projects on its main stem and tributary stream watershed. There are six main-stem (Corps) reservoirs controlling flow along the Missouri River.

Although they were not within the July flooded area, the six main-stem reservoirs had a significant impact on reducing the peak stage experienced along the Missouri River downstream from Gavins Point Dam. Without the main stem reservoirs, the 1993 peak flood stage would have been about 9 feet higher at Sioux City, 6 feet higher at Omaha, and 3 feet higher from Nebraska City to the mouth. Also, the duration above flood stage would have increased from zero to 60 days at Sioux City, from one to 67 days at Omaha, and from 25 to 80 days at Nebraska City.

Total storage in the main stem saw a dramatic increase during 1993. It is estimated that the total main-stem storage increased by more than 9 million acre-feet from June through August. As a combined total, the main stem and 61 tributary reservoirs stored in excess of 16 million acre-feet of water, much of which would have contributed to additional flooding.

The Kansas River tributary joins the Missouri River near Kansas City. The Kansas River and tributaries contain seven reservoirs: Harlan County, Wilson, Milford, Kanopolis, Tuttle Creek, Perry, and Clinton lakes. Farther downstream, the Chariton River is controlled by Rathbun and Long Branch lakes. The Osage River Tributary has the Harry S. Truman, Pomme de Terre, Stockton, Hillsdale, Pomona, and Melvern lakes.

All 25 Corps lake projects stored water in their flood-control pools during the 1993 flood. The maximum pool levels and percent of flood-control storage used that occurred at each Corps lake are listed in Table 4.

Water flows over the Coralville Dam spillway.

The maximum pool level exceeded the top of flood-control pool at Milford, Perry, Tuttle Creek, and Rathbun lakes. Water was stored in the surcharge pool and discharge through the spillway was required for the first time at Milford, Tuttle Creek, and Rathbun lakes. At Perry Lake the record level was 0.3 foot above the top of the flood-control pool and 1.1 feet below the spillway crest.

Regulation of flood-control storage at the 11 Bureau of Reclamation projects in the Kansas River basin is accomplished by Kansas City District through close coordination with the Bureau. Seven of the Bureau projects are located in the Republican River basin, and the other four projects are located in the Smoky Hill River basin. At their confluence, the Republican and Smoky Hill rivers join to form the Kansas River. The maximum pool elevation in 1993 was the highest pool level of record at four Bureau reservoir projects. The maximum pool level at Lovewell Reservoir exceeded the top of the flood-control pool by less than one-tenth of a foot. The maximum pool level and percent of flood-control storage used are shown in Table 5.

Storage levels at the Corps reservoirs in the Kansas City River basin peaked in

Table 4
Corps Of Engineers Lakes And Reservoirs
1993 Maximum Pool Elevation And Storages Used

Name of Lake or Reservoir	1993 Pool Elevation (ft. msl.)	Level Date	1993 Storage Data Percent Total Flood Control Storage
		Kansas River basin	
Harlan County	1951.6	7/31	16.2
Milford*	1181.9	7/25	126.5
Wilson *	1548.2	8/13	79.4
Kanopolis	1505.7	7/26	91.5
Tuttle Creek *	1137.7	7/23	104.7
Perry *	920.9	7/25	101.4
Clinton *	887.7	5/17	38.3
		Kansas City Metro Area	
Smithville *	874.3	7/28	81.9
Blue Springs	806.0	9/26	19.3
Longview	896.0	9/25	20.8
		Chariton River and Little Chariton River basins	
Rathbun *	927.2	7/28	107.1
Long Branch	799.0	7/26	76.9
		Osage River basin	
Melvern	1048.3	7/29	50.1
Pomona *	992.7	7/31-8/1	55.8
Hillsdale	926.7	7/29	63.6
Stockton	884.5	9/28	64.0
Pomme de Terre	*864.6	9/27	65.9
Harry S. Truman	735.2	8/2	79.2
		Des Moines River basin	
Saylorville*	892.0	7/13	107.6
Red Rock*	782.7	7/13	112.3
		Iowa River basin	
Coralville*	716.7	7/24	129.7
		Missouri River basin	
Fort Peck	2232.2	12/31	0.0
Garrison	1837.8	11/22	<1.0
Oahe	1611.6	9/09	27.0
Big Bend	1421.2	6/20	39.0
Fort Randall	1361.0	7/31	41.0
Gavins Point	1208.9	7/15	77.0

*Lakes with highest pool level of record occurring in 1993

Table 5
Bureau Of Reclamation Reservoir Projects
1993 Maximum Pool Elevation And Storages Used

Name of Lake or Reservoir	1993 Pool Elevation (ft.msl.)	Level Date	1993 Storage Data Percent Total Flood Control Storage
Republican River basin			
Bonny	3671.9	6/06	0.0
Swanson	2752.3	6/14	1.2
Enders	3101.6	6/24	0.0
Hugh Butler	2580.6	7/30-31	0.0
Harry Strunk	2371.4	7/28	20.5
Keith Sebelius	2296.0	7/28-31	0.0
Lovewell	1595.3	7/22	100.4
Smoky Hill River basin			
Webster *	1904.3	10/17	28.3
Kirwin *	1734.4	11/08	12.9
Waconda *	1487.0	7/29	94.1
Cedar Bluff	2117.2	7/30-31	0.0

*Lakes with highest pool level of record occurring in 1993

late July and early August, with the exception of Clinton Lake. Clinton Lake peaked in May and although most of the stored inflows were evacuated by July 1, the pool level nearly reached the May level in late July.

The total maximum storage of 4,435,900 acre-feet withheld at the seven Corps reservoirs is a new record total storage amount for the Kansas River system. It was equivalent to 90.1 percent of the total flood-control storage in the system.

Rathbun Lake on the Chariton River, Long Branch Lake on the Little Chariton River, and Smithville Lake in the Kansas City metropolitan area also reached maximum storage levels in late July, and the flood-control storage used varied from 76.9 to 107.1 percent. In the Osage River basin, four of the lake projects peaked in late July or early August and the other two in September. Although the Stockton, Pomme de Terre, Longview, and Blue Springs lakes reached maximum storage levels in September, they were also effective in reducing downstream peak stages in late July and early August.

Mississippi River Water Control Management Board and Committee

The Mississippi River Water Control Management Board is a continuing board consisting of the director of Civil Works serving as chair and division commanders from the five divisions bordering on the Mississippi River basin—namely, the Ohio, North Central, the Missouri, the Southwest, and the Lower Mississippi Valley divisions—as members.

The board's objectives are as follows:

(1) to provide oversight and guidance during the development of basin-wide management plans for the Mississippi River basin projects for which

the Corps of Engineers has water control responsibilities, and

(2) to serve as a forum for the resolution of water control problems among Corps of Engineers' divisions within the Mississippi River basin when agreement is otherwise unobtainable.

The board is responsible for overseeing procedures for maintaining and improving the coordination of water control management activities within the basin. It also oversees the development and use of facilities needed to coordinate water control activities.

The Mississippi River Water Control Management Committee is composed of senior technical staff from Corps Headquarters and five basin divisions. At the direction of the board, the committee assures continuing inter-divisional coordination of activities within the basin.

As the flooding that began in June continued into July, the committee held several teleconferences to exchange information and coordinate releases from the reservoirs. On July 16, when conditions worsened, the board initiated formal coordination. Most of the meetings used video-conference communication technology.

The board implemented several procedures to assist flood-recovery efforts. Detailed 30-day stage and flow forecasts for the upper Mississippi River and the Missouri River were made each week. A spread sheet was developed to show the relationship between the releases from the Corps reservoirs and the discharges at several control points along the Mississippi and the Missouri rivers.

The board evaluated a proposal to reduce reservoir release rates upstream of St. Louis to (1) assist in the resumption of navigation for stages below 37.0 feet at the St. Louis gage, and (2) reduce the effects of long-term flooding in communities by returning to stages below the flood stage of 30.0 feet at St. Louis as rapidly as possible. Significant benefits were identified in reducing releases from the upstream projects in order to achieve the 30-foot stage at St. Louis. As a major part of this effort, the board evaluated alternative release schedules from the Harry S. Truman Dam to reduce the stage at St. Louis.

Committee teleconferences continued on a weekly basis during July, August, and early September. Current hydrologic and meteorologic conditions in the Mississippi River basin were discussed by each of the division committee members.

Subsequent to the flood, the board initiated the development of a main-stem Mississippi River numerical model that would be used to provide forecasts for both stage and discharge. The model will be able to handle the effects of levee breaks and be capable of addressing short-term (one to six

National Guard sandbag operation in Hamburg, Iowa.

days) and long-term (30 days) forecasts. The five division offices (North Central, Ohio River, Missouri River, Lower Mississippi Valley, and Southwestern divisions) with assistance from Hydrologic Engineering Center are developing an integrated hydraulic model of the Mississippi River main stem and tributaries.

Emergency Management

Advance Measures

In March, several districts conducted flood fight training classes in response to the possibility of spring flooding. These exercises provided hands-on training for area flood engineers.

After completing the seminars, area flood engineers contacted their respective areas and cities about potential spring flooding and the importance of advance measures of planning and preparation to minimize damage to vital facilities, including water-treatment plants and sanitary and storm systems.

Each city with a flood history was encouraged to establish a flood organization and written plan for conducting flood-fighting operations and to develop plans for evacuations for certain areas if necessary. Most cities and communities have a flood-emergency contingency plan ready for implementation when needed.

Unlike spring snowmelt flooding, which allows time for flood forecasting, the unusual and extreme rainfall events of the summer of 1993 allowed little time—if any—for advance flood notification. Advance measures were therefore very limited.

Flood-fight Activities

Under Public Law 84-99, the Corps of Engineers may provide emergency assistance for flood-response and post-flood-response activities to save lives and protect improved property (i.e., public facilities and services and residential and commercial developments) during or following a flood. Acting for the Secretary of the Army, the Corps is also authorized to undertake activities such as disaster preparedness, advance measures, emergency operations, the rehabilitation of flood-control works threatened or destroyed by flood, and the provision of emergency water due to contaminated sources.

District Emergency Operations Centers (EOC) were activated and flood-area engineers dispatched to areas to provide technical assistance. This assistance included:

- Field EOCs were established to provide 24-hour-a-day service to local communities.
- Operation of permanent flood-control projects;
- Emergency construction techniques for levee raises, closures, and sandbagging operations; and
- Monitoring flood-protection works.

Corps personnel provided technical engineering support such as mechanical and structural design assistance, hydraulic and hydrologic forecasting, and geotechnical soil-stability assessments. Field personnel worked in teams of two—one member of each team was an engineer or an engineering technician.

Based on the past experience of the area flood engineers, information was provided to the communities regarding areas of potential seepage, sand boils, and erosion potential. Information regarding emergency interior drainage treatment facilities and technical assistance on filling sandbags, the proper use of polyethylene and the sizing and placement of portable pumps was also provided to the communities.

As the flood progressed, it soon became apparent that human resources would not be enough to handle the work load. To solve this problem, the districts involved in the flood sent out requests for personnel to other divisions and districts and other agencies, such as the Bureau of Reclamation. In some districts, retirees who were familiar with dams and levees were recalled to supplement the staff.

St. Paul District. The St. Paul District EOC was activated in March for the response to early spring flooding along the Minnesota River. Following this event, the district EOC was on standby until the June flooding. The district again initiated emergency operations and activated the district EOC on June 20, 1993. Flood engineers were dispatched to Black River Falls, Wis., and to communities along the Minnesota River.

Approximately 120 Corps of Engineers' Navigation Branch personnel assisted in flood-fight

Filling sandbags in Ste. Genevieve, Mo.

efforts at the Mississippi River locks and dams, and 61 flood-emergency response personnel provided assistance to communities.

The district flood-response organization was directed by the flood executive officer, who operated out of the district EOC. Administrative support to the operation was managed by the EOC staff with the chief of Emergency Management as head. Flood area engineers were dispatched from the district EOC.

Since the flood event resulted in no major emergency construction, no field EOC were established. Local communities and counties provided support to Corps of Engineers personnel, as needed.

The district's flood engineers worked out of the Wisconsin's alternate state EOC, which had been established in Black River Falls. The only major flooding problems in the St. Paul District portion of the state of Wisconsin was at Black River Falls. The state's EOC remained at Black River Falls for several weeks.

Rock Island District. The Rock Island District EOC operated 24-hours a day from June 18 through Aug. 31. A total of up to 220 employees were deployed to field EOCs.

The district is divided into nine flood emergency areas. There was flooding in all but one of those areas.

On June 24, the Burlington, Iowa, and Quincy, Ill., area EOCs were mobilized due to a forecast of high Mississippi River stages in the area. Both operated 24-hours a day. The Quincy EOC grew to a maximum staff of 52 people. Technical assistance was provided to the towns and drainage districts on a 24-hour basis from July 2 to Aug. 2. In addition, three geotechnical teams were brought in to provide geotechnical assistance on the complex flood fighting problems.

Federal Levee L246 at RM 241 on the Missouri River.

monitor high flow releases and rising pool elevations at Coralville Lake. It also served as a distribution point for sandbags and pumps to surrounding communities in the Iowa and Cedar river basins.

Engineers were also on site at Saylorville and Red Rock reservoirs to prepare downstream areas for record spillway releases.

On July 5, several Corps employees were sent to Wapello and Van Buren counties in Iowa to assist local officials. A field EOC was established in the central fire station in Ottumwa, Iowa. Technical assistance provided resulted in protecting the Ottumwa Water works, the downtown area on the left bank of the Des Moines River in Ottumwa, the city of Eddyville, lift stations in numerous communities, and major transportation routes. A 24-hour levee surveillance was organized using Iowa National Guard units.

Flood area engineers were dispatched to the Des Moines area on July 9 to coordinate flood-fighting efforts with the local communities. A Corps EOC was established at the city of Des Moines EOC located at East High School.

On the morning of July 11, the city of Des Moines lost its water supply when the water-treatment plant's municipal levee overtopped.

For the next three weeks, Corps personnel assisted in flood recovery efforts which included: the recovery effort at the water-treatment plant, monitoring the city's levee systems, contracting emergency flood-fighting efforts at the failed southeast Des Moines River floodwall, coordinating interior drainage pumping, and under FEMA tasking, providing potable water to the city of Des Moines.

On July 1, drainage districts and towns in the Quincy area started raising their main-stem sand levees 3.5 to 4.0 feet by using bulldozers and pushing sand from the landside slopes. The main focus during this phase was to raise the levee system to withstand a flood stage of 32 feet at the Quincy gage. Flood stage at Quincy is 17 feet.

In one area, to control seepage, Corps contracts furnished 12 wide-track bulldozers and provided three Corps-owned bulldozers to continually dress landside slopes to minimize sand erosion. The bulldozers also placed additional levee material where needed.

In early July, a temporary EOC was established at the Coralville Administration Building to

St. Louis District. The St. Louis EOC changed from standard operation to 24-hour operation on July 8. Several unprotected river towns and urban areas suffered severe flooding including: Grafton, Kimmswick, Arnold, Festus, Crystal City, Ste. Genevieve, Hardin, Kampsville, Meredosia, Des Pares, and Lemay.

Residents of Grafton, Ill., began evacuating on July 10. About 150 homes were flooded, and more than half of the town's 900 residents were evacuated. The town was almost inundated by the flood, and residents are considering moving the town to higher ground.

Construction of an earth and sandbag levee at Kimmswick, Mo., was completed on July 5, providing protection to 46.0 feet (St. Louis gage), and pumps were used to remove interior water from heavy rainfall and seepage. On July 20, an evacuation notice was issued, and the earth levee was raised using sandbags and earth fill, providing protection to 48.0 feet on the St. Louis gage. The levee was again raised on Aug. 2 to 50.0 feet using sandbags. On Aug. 13, some flooding occurred in streets due to heavy rainfall, but pumps were able to remove the excess water. The emergency protection was successful, preventing damage to most of the town.

Alton, Ill., is located 20 miles north of St. Louis along the Mississippi River. Throughout July, sandbags and other materials were used to protect low-lying areas. On Aug. 1, the water-treatment plant at Alton and 75 businesses were flooded when water seeped beneath a buckled street. Water service was cut off to 72,000 customers. The levee protecting the older portion of the downtown area failed.

No federal levees or floodwalls provide flood protection in St. Charles County in Missouri. About 6,000 to 8,000 people were evacuated from the lowlands. The Kuhs Levee breached at three locations, and overtopping occurred at Brevator and Heitman in early July. There were dozens of breaks in various levees throughout the county, with each averaging 500 feet.

On July 9 in Arnold, Mo., Highways 231 and 61/67 bridges were closed and individual sandbagging began in residential areas. From July 20 to Aug. 1, several sandbag levees were overtopped, flooding homes in the area.

A sand levee was built around a sandstone mine near Festus and Crystal City, Mo., and work began to close three mine entrances. On July 12, sandbagging continued for individual homes and businesses and the sandstone mine was near flooding. On July 18, Crystal City shut down and sealed one of its water-supply wells. By July 21, Crystal City's water-purification plant was no longer in operation and water was supplied by Festus. The joint sewage-disposal plant for both cities was also put out of operation in mid-July and was inoperable for several months. On Aug. 1, part of the downtown Festus levee was overtopped.

St. Louis, Mo., city emergency-management officials decided on July 11 to evacuate 200 families in the South Broadway and River Des Peres areas. Volunteers worked around the clock to reinforce 2 miles of non-federal levee along the River Des Peres, which is an open channel interconnected to a storm-water drainage system at the southern edge of the city of St. Louis. On July 16, 120 homes in the Lemay area were evacuated for fear the rising River Des Peres would isolate them.

Between April 16 and 27, the Corps provided pumps, sandbags, and rolls of plastic to the city of Ste. Genevieve for the spring flood. Sandbagging began in earnest on July 1 in preparation for a forecasted crest of 40.5 feet at the Chester, Ill., gage.

Several sanitary manholes in Ste. Genevieve began spewing water, and at least two private sewer lines were ruptured, forcing water out onto the ground.

On July 18, the decision was made to evacuate those parts of the city that would be affected should there be a levee failure. Areas behind the levees were saturated, and rock was placed in soft spots. Portions of the city's roads, sewers, and water lines were destroyed.

Problems at the Salisbury Pump Station Levee were related to several large, leaking storm-sewer pipes. The Metropolitan Sewer District attempted to line the leaking pipes during the flood, but were unable to lower the water level enough to do the work.

Leaking pipes in the ground near the levee caused the ground to settle. During a 24-hour period, a week before the crest, 100 20-ton truck loads of rock were dumped in one sinkhole alone.

Lock and Dam 25, Cap au Gris, Mo.

Railroad tracks landside were suspended in the air, and a telephone pole sank to about half of its original height. Between July 29 and 30, the levee settled 6 inches at the landside toe, 2 inches just down the slope from the landside crown, and 0.5 inch on the riverside edge of the crown just north of the pumping station. Cracks formed in the levee crown and landside slope.

In an effort to hold the line of protection in case the levee section partially or totally failed, the Corps began constructing a rock berm on both sides of the levee upstream and downstream of the pumping station. Rock placement continued around the clock. On Saturday, the day before the crest, the riverside and landside berms were completed. To further complicate matters, on the evening before the crest (July 31) six tornadoes touched down in the St. Louis metropolitan area. In spite of all the difficulties, the levee held.

On July 22, the Corps was informed that a large sandboil had developed behind the St. Louis Floodwall at Riverview. On July 23, a sinkhole and resulting geyser of water had developed behind the wall. The Metro Sewer District placed approximately 100 tons of rock behind the wall, closing off the sinkhole. A plan was developed to construct a rock ring levee inside of the floodwall, and to place rock fines riverside of the wall to seal the pipe and stop the underseepage. Construction of the ring levee continued on a 24-hour basis, and by July 25 the levee had been completed.

Kaskaskia Island, Ill., was created more than a century ago by a Mississippi River flood. It is mostly farmland except for two small communities and a small museum. On July 21, flood fighters spotted a threatening breach on the Kaskaskia levee. Shortly after midnight, 125 families were awakened and warned to evacuate. On July 22, the levee was undermined and breached. Remaining residents fled on two Corps of Engineers' barges. Within a few hours, the island was completely submerged.

Omaha District. The Omaha District EOC operated from the end of February through March, and again from the end of June to the end of December. A total of 130 employees were deployed to the field to provide technical assistance. Advance measures included the following:

On July 6, an Omaha District hydraulic engineer was dispatched to the Iowa Great Lakes region (Spirit Lake, Lake Okobojii, and Lower Gar Lake) to provide technical assistance to local planners. On July 9 and 10, six more district personnel were dispatched to determine lake levels based on possible precipitation, determine the best drawdown rate, and design emergency spillways at Spirit and Lower Gar lakes. For three weeks, this team assisted the Iowa National Guard to determine the best locations for sandbagging activity, design and contract construction of the spillway, and to time releases in a way that wouldn't exacerbate damages downstream.

On July 28, a Corps team was sent to Jamestown to evaluate Pipestem Dam on the Pipestem Creek (a tributary of the James River) in North Dakota. They reported signs of distress to the dam and a record pool elevation. Release rates were determined and the structural integrity of the dam was evaluated and found to be sound.

The same team evaluated the Jamestown Dam, a Bureau of Reclamation dam above which the Corps controls flood storage. The team found the record pool required a fairly high release rate to prevent a potential dam failure because of a hydrologically inadequate spillway. Development in Jamestown had encroached on the river and residents were given information on the probable results of a dam failure and offers of sandbagging assistance. Releases were then made as needed. A channel clearing effort was designed and managed by the Garrison Area Office.

During the summer floods, the Missouri River Project Office led the flood fights in Peru, Nemaha, and Hamburg, Iowa, and in the Missouri Valley in Nebraska and Iowa. The Lewis and Clark Lake Office led the fight in Rock Rapids and Rock Valley, Iowa, and in Bismarck, N.D.

Kansas City District. Emergency-response activities were conducted throughout the entire Kansas City District, but most of the activities were concentrated along the Missouri and Kansas rivers. Flood fighting was conducted on three levee units, two federal units and one non-federal levee.

At the North Kansas City Unit Levee, located in Kansas City, Mo., the south pumping plant was damaged during the May 1993 flood and as river stages continued to climb, contingency plans developed earlier were implemented and a contract issued to expedite construction of a temporary ring levee to protect the Kansas City Downtown Airport, railroad yards, a business area, and other structures.

Missouri River Levee System L-246 is located on the left bank of the Missouri River and includes three tributaries—the Grand River, Chariton River, and Mussel Fork. It began experiencing sloughing and slides as a result of saturated ground conditions. As conditions continued to deteriorate, it was necessary to issue an emergency-operations letter contract to construct a rock access road to permit reinforcement of the levee embankment at two of the slide locations in an effort to preclude further damage. The unit was overtopped along the Grand River on July 26 and breached along the main stem levee on the Missouri River.

The Monarch Chesterfield levee sustained a major breach in the upstream reach the night of July 30. The breach allowed flood waters to inundate 5,632 acres. It was necessary to evacuate the entire interior area. Flood waters receded, initial cleanup operations commenced, and contracting procedures were expedited to proceed with the repair of the primary upstream breach. However, before the initial repairs could be initiated, additional heavy rainfall occurred throughout the basin, causing another rise in river levels with a predicted crest that would again subject the interior area to flooding. The emergency situation required a modification to the initial contract in an attempt to provide partial protection in the immediate vicinity. It quickly became evident that this effort would be ineffective in the increasingly wet and muddy field conditions. A joint effort by the city of Chesterfield and St. Louis County was initiated to raise the elevation of a north-south road by having a contractor haul and place rock. The Corps of Engineers assisted in the flood-fight effort. Round-the-clock efforts resulted in holding back the flood waters throughout the area, and additional major devastation was averted.

Navigation

The upper Mississippi River Navigation System is an integral part of a broad regional, national, and international transportation network. As such, it has played a key role in the economic growth and development of the upper Midwest, including Minneapolis-St. Paul, Minn., Dubuque, Iowa, the Quad Cities, Iowa and Ill., St. Louis, Mo., and Peoria and Chicago, Ill. The river system provides an important link both into and out of America's heartland.

Agricultural products, particularly grain, are the primary commodities moving out of the eight-state growing region served by the rivers. The river system also provides a major artery for the transport of bulk commodities into the region for industrial productions.

The Mississippi River, one of the major highways for this traffic, was closed to shipping above St. Louis due to the Flood of 1993. (See Table 6.) The flood's impacts on the transportation sector were massive and far reaching. More than 1,000 barges were stranded on the upper Mississippi, Illinois, and Missouri rivers, with costs to the towing industry estimated at $700,000 per day. This did not include the barges massed near Cairo, Ill., awaiting the resumption of navigation.

The American Waterway Association reported that 7 million short tons of cargo worth an

Flooded control house at Lock and Dam 21, Quincy, Ill.

estimated $1.6 billion were held up by river closings—$864 million worth of grain, $224 million in petroleum, $192 million in coal, $144 million in chemicals, $64 million in iron and steel, and $112 million in miscellaneous products.

Fifteen percent of the country's freight moves by river barge. Typical shipments consist of a dozen or more 195-foot-long barges tied together and guided by a towboat.

As the water rose, lock crews began removing or protecting all lock operating equipment and all lock-site buildings. Lock crews placed sandbags and bulkhead closures around central control stations, control houses, maintenance buildings, and standby generator buildings. Electric motors, tow haulage units, and other machinery were removed and raised to higher ground. At the same time, plans were formulated for the reinstallation of equipment and anticipated repairs that would be needed to resume operation of the locks for navigation traffic.

Five Mississippi River locks in the St. Paul District were closed for short periods during the summer flood. The Rock Island District had 12 lock closures varying from 19 days to 52 days during the summer. The St. Louis District's three locks were closed a total of 73 days during the period April 22 to July 7. (See Table 6.)

Table 6
Upper Mississippi River Navigation High Water Lock Closure Dates

L&D	River Mile	Date Closed	Date Reopened	Days Closed
3	797.0	25 June	30 June	6
4	752.8	24 June	25 June	2
8	679.2	28 June	2 July	5
9	647.9	28 June	3 July	6
10	615.0	25 June	9 July	14
11	583.0	26 June	14 July	19
12	556.7	25 June	22 July	30
13	522.5	26 June	23 July	28
14	493.3	29 June	20 July	22
15	482.9	29 June	21 July	23
16	457.2	19 April	3 May	15
		25 June	2 August	38
17	437.0	6 April	11 April	6
		18 April	3 May	16
		25 June	9 August	45
18	410.5	20 April	3 May	14
		25 June	9 August	45
19	364.2	30 June	5 August	36
20	343.2	20 April	7 May	17
		7 May	10 May	3
		25 June	11 August	47
21	324.9	21 April	3 May	12
		4 May	10 May	7
		26 June	11 August	46
22	301.2	21 April	11 May	20
		26 June	17 August	52
24	273.2	22 Apr	3 May	12
		5 May	10 May	6
		29 June	22 August	55
25	241.2	25 April	3 May	9
		1 July	22 August	53
26	203.0	10 July	17 August	39
27	185.3	7 July	20 August	45

By July 6, navigation was closed on the Missouri River from river mile 293 to the mouth. Parts of the river were closed for almost two months (49 days).

At the height of the flood, 400 miles of the Mississippi River were closed to commercial and recreational traffic. It was more than eight weeks before all the locks were reopened.

After a consultation meeting with the Corps of Engineers and River Executive Task Force representatives to discuss details for resuming navigation, the Coast Guard imposed numerous restrictions on navigation in an effort to avoid groundings and further deterioration of the channel and levees. The Corps provided general channel depth information at specific locations and copies of hydrographic surveys for each of the problem reaches, which were distributed to towboats as they passed through the locks. The Coast Guard was also provided with information on a regular basis for their use in preparing broadcasts and notices to mariners.

Recovery

Every lock on the Mississippi River encountered a unique set of problems. Lockmasters at each lock determined what parts and equipment they would need even before the flood crest. They also determined what parts could be saved, dried, and repaired, and what equipment would be replaced. The locks were ready for operation before the Coast Guard had determined the river to be safe for traffic.

The extended spring high water and abnormal June-July flooding resulted in severe shoaling of the channel and required extensive dredging in the St. Paul and St. Louis districts. There were several channel closures as a result of the combination of shoaling, vessel groundings, and the efforts of the vessels to get free.

Despite the critical situation for navigation, every effort was made to avoid adverse environmental impacts from dredged material placement. Nearly 80 percent of the material was placed at locations where the material was considered beneficial. Most of the remaining 20 percent was placed at designated temporary sites where long-term plans are to remove the material and transfer it to permanent beneficial-use locations.

On the Missouri River, impacts to the navigation projects were substantial in that stone-filled dikes and revetment structures were severely damaged in at least 45 locations and will have to be repaired or replaced. The side channel areas were also severely eroded allowing for potential channel change and shoaling conditions to develop within the channel.

Federal, State, and Local Coordination

A flood, especially one of the magnitude seen in the Flood of 1993, cannot be fought effectively by any single agency. The Corps of Engineers had extensive, daily contact with federal, state, and local agencies before, during, and after the flood.

The Corps dealt extensively with the Federal Emergency Management Agency (FEMA), which is a focal point of disaster assessment and assistance by the federal government and must respond quickly to aid persons in declared disaster areas.

During the flood, a levee near Warsaw, Ill., was overtopped, inundating an area 8-miles long and up to 6-miles wide. Within this floodplain area was a small town, riverside cabin communities, and many farmlands. FEMA used this area to conduct a pilot study in "rapid situation-assessment mapping." A FEMA contractor used the latest in Global Positioning System and Geographic Information System (GIS) technology. They made an aerial inventory of the flooded structures in the area and relayed the information to GIS files in Washington, D.C., and the Rock Island District.

FEMA formed a team of experts from the Rock Island District, together with the contractor, to produce maps needed for disaster response, recovery efforts, and risk mitigation. This effort demonstrated that observations of disaster conditions can be quickly transformed to paper map products and computer databases, which can be used easily by other agencies concerned with the disaster.

The Corps also worked under FEMA taskings to provide potable and non-potable water to areas where water service had been disrupted.

The National Weather Service and Corps of Engineers personnel exchanged data and analysis on a continual basis. These data included reservoir releases, river conditions, stage and flow forecasts, current weather conditions, and forecasts.

Other federal agencies with whom the Corps coordinated included the U.S. Coast Guard, Department of Transportation, Soil Conservation

Service, U.S. Fish and Wildlife Service, U.S. Geological Survey, and the Environmental Protection Agency.

Corps liaison officers were dispatched to state emergency operation centers. There they coordinated requests for supplies and equipment, briefed governors and state officials on river stages, USACE activities and authorities, and levee data, and made use of National Guard assets to reposition sandbags and pumps.

Flood-area engineers and reconnaissance personnel kept in daily contact with local officials. Coordination with railroad, country road, and local utility personnel was also necessary for flood-fight and recovery activities.

The Corps worked closely with local law-enforcement agencies and levee and drainage district personnel.

The Remote Sensing/GIS Center at the Corps of Engineers Cold Regions Research and Engineering Laboratory in Hanover, N.H., has developed Flood Emergency Base maps for the Mississippi, Missouri, Illinois, and Des Moines rivers. They are drawn to a 5,000-meter grid. The data used to create these maps are also available in digital form over the Internet computer system. These base maps can be used to show inundated areas and federal and private levee district, for example. A sample base map is shown on Plate 9.

Black River at Black River Falls, Wis.

Section V
Flood-Damage Description and Appraisal

General Description of Damage

As a result of the flood, the Federal Emergency Management Agency declared 505 counties in nine states eligible for either individual or community assistance. Of the nine states, the most severe damage occurred in Iowa, Illinois, and Missouri. Table 7 shows the distribution by state and Plate 7 shows the plan location of the different counties.

This natural disaster killed 47 people and forced 74,000 people from their homes. It also disrupted commercial activity all along the Mississippi and Missouri rivers and adjacent areas and destroyed thousands of acres of crops. In addition to the crop losses, many farms also lost vital structures, facilities, and equipment.

An estimated 72,000 private homes either were washed away or suffered major damage. Between 35,000 and 45,000 commercial structures were damaged. Virtually all forms of transportation on and across the Mississippi River were interrupted by the flood. Along the length of the Mississippi River that forms the western boundary of Illinois, more than 1,000 miles of roads were closed and nine of the 25 non-railroad bridges were shut down. Estimates put the combined total losses at $15.6 billion.

Table 7
Federal Disaster Area Counties by State

State	# of eligible counties	% of state's counties
Iowa	99	100
Missouri	85	75
North Dakota	39	74
Wisconsin	48	67
Minnesota	53	61
South Dakota	39	59
Nebraska	52	56
Kansas	51	49
Illinois	39	38
Total	**505**	

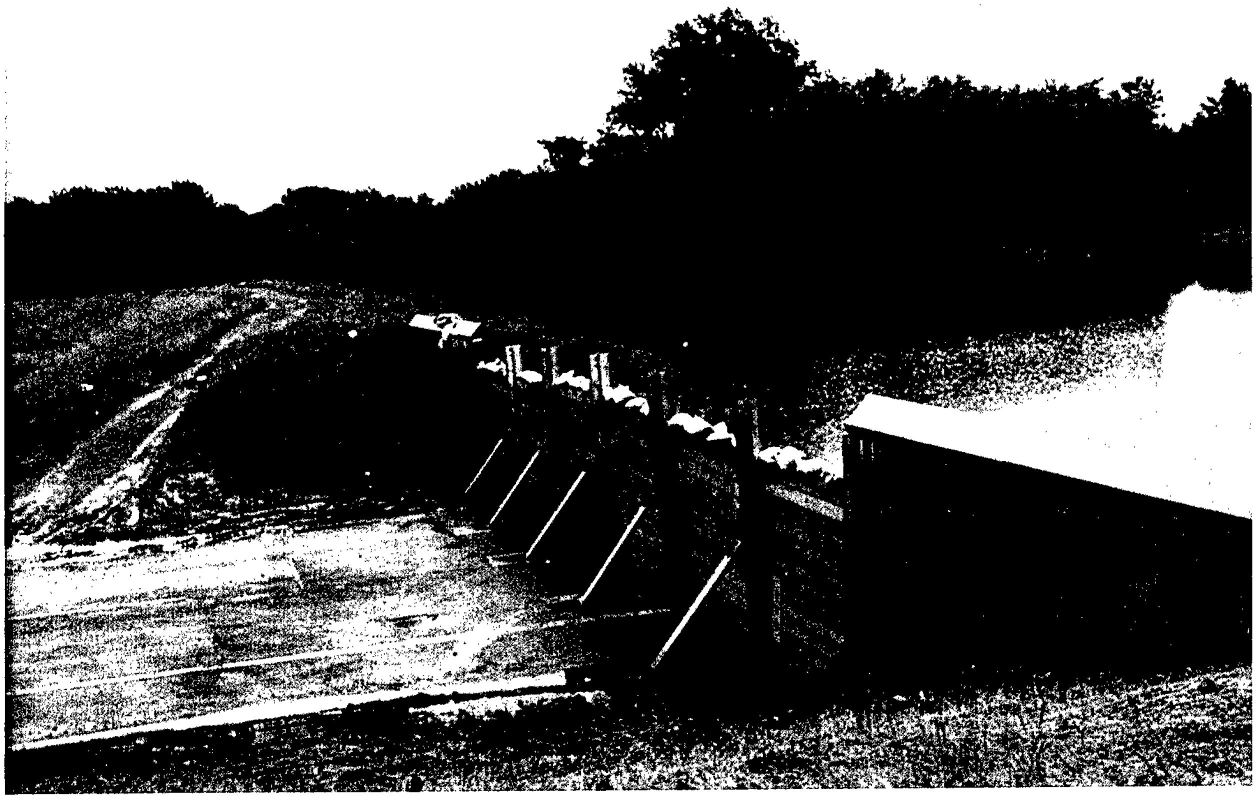
See Plate 7 for more information.

General Appraisal of Damage Experienced

The severity and duration of the 1993 flood event has exceeded the capability of the existing database to accurately predict flood-damage parameters. Current data are based on extrapolation of the 1973 flood information and professional judgment. Field verification has not yet been accomplished.

According to the Minnesota Department of Natural Resources, Minnesota flooding affected approximately 6.7 million acres of agricultural land, causing in excess of $1 billion in agricultural damage. Individual, family, and business losses are estimated at $155 million. Damage to public facilities, such as roads, bridges, culverts, dams, buildings, trails, parks, and cleanup is estimated at $52 million.

Damage totals of at least $930 million in Wisconsin were reported by the Wisconsin Department of Natural Resources in December 1993. Eighty-six percent of the damage ($800 million) was related to agriculture. At least 4,700 homes were damaged by the floods, 2,500 people were evacuated, and the damage may exceed $46 million (five percent of the total damage). This total does not include the costs of temporary housing and meals, evacuation activities, or damaged personal possessions. Private business losses exceeded $31 million (3.3 percent), much of it related to shutdowns and damage to goods and supplies stored in basements. Public damage reached $42.6 million (4.7 percent), including roads, bridges,



Closure structure at State Highway 93 at Henderson, Minn., on the Minnesota River.

buildings, dams, and levees. Utilities claimed $9.2 million in damage (1 percent).

Damage estimates in the Rock Island District are not completed, but will probably exceed $1 billion. More than two dozen levees in the Rock Island District were overtopped by the flood waters, flooding more than 190,000 acres of farmland and several small towns.

Estimated flood damage in the St. Louis District totals $1.3 billion for areas without protection, which included essentially all non-federal levees that were overtopped. About $87 million in damage occurred in areas with federal protection where federal levees were overtopped or breached.

Damage from floodwaters was staggering. According to the Soil Conservation Service, about 10 million acres of farmland were flooded at least once since the spring of 1993 in nine Midwest states. Iowa and Missouri accounted for half of the flooded farms and total crop damage, which is estimated to be nearly $5 billion.

The destruction could wipe out many farmers' earnings for the entire year and could make some land difficult to restore. The flood left farmland covered with sand, silt, driftwood, trees, and other debris.

A high percentage of crop acres in Kansas City District floodplain areas suffered losses, due to the overtopping of nine of the 15 units in the federally-constructed Missouri River Levee System and virtually all of the non-federal farm levees in the district. More than 1.4 million crop acres are classified as failed due to the flood, resulting in damages totaling $359 million.

Damage to cities and small towns in the Kansas City District are estimated at $661 million. Damage to the public sector primarily falls into two categories: damage to highways, bridges, and roads, including structural damage and losses from traffic delays and detours; and damage to public utilities, particularly water-supply facilities and wastewater-treatment plants. Damage to the public sector are estimated at $274 million.

Although all the federal urban local protection levees in the district held during the flood, most of them needed at least minor repairs. The total cost of repairing federal levees in the Kansas City District currently is estimated at $41.9 million. It is estimated that the repair costs for non-federal levees, including those levees not repaired by the Corps, will exceed $300 million.

The high cost of damage in the Midwest is largely due to the tremendous agricultural damage. Most previous large floods occurred early in the spring, and many farmers were able to plant once the floodwaters subsided. In 1993, the late start and long duration of flooding prevented many farmers from planting a crop in the first place, and if they did, many fields were flooded later, giving no chance to replant or salvage the crop.

The collection of economic flood data was coordinated by the Lower Mississippi Valley Division office. The task was completed at the end of July 1994, too late for enclosure in three of the appendices. The Kansas City and Omaha districts did gather and include economic dollar damage data, which were compiled by their own forces or procured from other government agencies (e.g., the Federal Emergency Management Agency, Soil Conservation Service, and U.S. Department of Agriculture). Dollar value damage, by county, is tabulated in Appendix D, tables 12 and 13. (See sample of summary on Plate 8.)

In the Omaha District, for example, the total FEMA assistance in the 137 counties alone amounted to $78 million dollars. Of this amount, $51.5 million was for public and private non-profit assistance and $26.5 million was for individual assistance. An additional $16.7 million was loaned through Small Business Administration assistance.

The 1993 flood-damage data will be included in the Flood Plain Management Assessment of the Upper Mississippi and Lower Missouri River and their Tributaries report, to be published in June 1995.

General Appraisal of Damage Prevented by USACE Projects

The St. Paul District's flood-control projects worked as designed to prevent substantial damage within the district. When the Flood of 1993 ended in August, the district's flood-control projects had prevented $217 million in damage in North Dakota, Minnesota, Wisconsin, and Iowa—$209 million in Minnesota and North Dakota alone.

The reservoirs (Hwy 75 and Lac Qui Parle) were operated to the extent possible to reduce damage on the Minnesota and Mississippi rivers. The estimated value of total damage prevented by these reservoirs during the flood was $2.8 million.

Building, raising, and strengthening federal flood-control projects and levees and the operation of the three reservoirs in Iowa prevented an estimated $1.1 billion dollars in damage.

The reservoirs (Coralville Lake on the Iowa River and Saylorville and Red Rock lakes on the Des Moines River) were operated to the extent possible to reduce damage on the Iowa, Des Moines, and Mississippi rivers. The total damage prevented by the three reservoirs during the July 1993 flood was $672 million dollars. About half of this was due to preventing overtopping of levees on the Mississippi River. Preliminary estimates of $472 million in damage prevented by other Corps projects are based on existing damage curves from previous reports.

Flood damage prevented by Corps projects in the St. Louis District include: levees and floodwalls—$2.9 billion; federal and non-federal flood-fight levees—$118 million; and, St. Louis District reservoirs—$645 million.

On the Missouri River main stem, an estimated $130 million in damage has been prevented; the tributary reservoirs prevented an estimated $89 million in damage; and, the levee projects prevented $225 million in damage.

Damage prevented by Kansas District reservoirs is estimated at $4 billion.

Local protection levees, including those at Kansas City and Topeka, Kan., prevented an estimated $4.7 billion in damage. Levees in the Missouri River levee system, which primarily protect agricultural land, prevented an estimated $188.3 million in damage.

Milford Lake spillway releases and headcutting.

Section VI
General Flood-Recovery Activities

After the waters of the Mississippi River receded, flood-recovery efforts began in towns and cities in the Midwest. Key post-flood issues included the cleanup of toxic materials in flooded areas and the question of which levees to rebuild along the river.

The flood-recovery efforts throughout the middle and upper Mississippi and Missouri river basins were coordinated by a levee task force that was established to ensure that all emergency repairs were completed to restore flood protection before the spring 1994 flood season. The accelerated schedule was necessary to avoid winter's frozen soil and river ice, which make needed repairs difficult if not impossible.

Prior to repairs, the Corps informed each levee district of the possible alternatives to repairs, which included the creation of wetlands and/or relocation through land purchases in coordination with the Federal Emergency Management Agency, Fish and Wildlife Service, Environmental Protection Agency, and the Soil Conservation Service. Louisa County Levee District No. 8 in Iowa is the only one to consider a buyout.

Of the 543 damaged levees in the Midwest that applied for emergency repairs from the Corps, 270 were rejected as being ineligible for Corps aid. Most of the 270 rural levees either did not meet Corps standards or the forms were not properly filed.

St. Paul District. Since flooding in the St. Paul District was not as severe as in the rest of the flood area, post-flood repairs cost only $80,000. This work included repair to one federal and one local levee. Dredging was also done on the navigation channel to remove shoals that floodwaters left behind.

Rock Island District. Within the Rock Island District, there are more than 300 levee districts with levee systems. Of those levees, 96 are eligible for Corps assistance under emergency authority (Public Law 84-99). Even though most of these levee systems performed successfully and prevented millions of dollars in damage, 33 were damaged to an extent that warranted Corps emergency work. This included 19 large agricultural levee districts where levees were overtopped and subsequently breached. Levee breaks ranged from a few hundred feet to more than 4,000 feet.

Work included repairing breached or overtopped levee systems, repairing pumping stations, and restoring interior or exterior portions of levees damaged by wave wash, and, in some instances, included the removal of wave-washed soil from farmlands when the material was needed elsewhere.

The work was accomplished through hydraulic dredging by contract dredges and numerous heavy-machinery contractors. Contractors partnered with Corps employees to return flood protection to more than 360,000 acres of agricultural and urban property within the Rock Island District.

Because of the magnitude and extent of the flood damage to levees and pump stations, the uncertainty of the weather, and the need for careful consideration of environmental impacts, complete levee rehabilitation in the Rock Island District took approximately one year. The estimated total cost of repairs is about $49 million.

St. Louis District. In the St. Louis District, initial repairs have been completed for 24 damaged levees where they were required. These repairs were delayed because the flood waters stayed so high for so long and permanent repairs did not begin until the spring of 1994. Repair work is also progressing on several federal pump stations.

The Corps has finished the $1.3 million job of patching the Harrisonville, Ill., levee near Valmeyer and the Nutwood and Hartwell levees along the Illinois River. The Corps has also repaired two small levees along the Mississippi River south of Clarksville, Mo.

The total cost for initial levee repairs in the St. Louis District is estimated at $41 million.

Omaha District. In the Omaha District's 1993 flooded area, there were 31 federally constructed levees and 26 non-federally constructed levees that were eligible for the Public Law 84-99 program and another 174 levees that were documented. All levees in the Omaha District are locally maintained. Of these, 13 of the federally constructed levees and 16 of the eligible non-federally constructed levees were damaged, as were 137 of the other levees.

A total of 83 requests for levee rehabilitation assistance were received as a result of the summer flood event. Several hundred miles of levee systems were evaluated. Projects that were determined to be ineligible for Corps assistance were forwarded to the levee rehabilitation task force at the respective state disaster field offices for consideration by other federal agencies.

A total of 16 contracts were awarded under PL 84-99—seven in fiscal year 1993 and nine in fiscal year 1994. More than $375,000 was spent in fiscal year 1993 for levee repair with an additional $7,181,000 spent in fiscal year 1994. All levees were floodworthy by spring 1994.

Several hundred miles of levee have been repaired by the Omaha District.

In addition to the reconstruction of levees, the Omaha District worked with the state of Nebraska to determine potential sites for ice-jam prevention structures to establish a network of ice spotters and a data collections and dissemination network. A Section 22 Study and a General Investigation Study were initiated to further study the causes of and prevention of flooding along the Platte River in Nebraska.

In early August, the Federal Levee Rehabilitation Task Force established the need for interagency coordination within the Disaster Field Office. The concept was to provide a central focal

Hydraulic dredges repairing the damaged Sny levee.

point for quick review of all levee rehabilitation applicants and allow for consistent policy adherence among the affected states. In addition, the memorandum from the Executive Office of the President, Office of Management and Budget, provided additional guidance for ensuring that all relevant organizations had an opportunity to comment on projects and offer other alternatives to levee restoration. The overall goal was to achieve a rapid and effective response to the damaged flood-control system that would minimize risk to life and property, ensure a cost-effective approach to flood-damage mitigation and floodplain management, and protect important environmental and natural resource values.

When the FEMA Missouri DFO made the transition from response to recovery on Aug. 19, the Corps was actively involved in interagency levee-rehabilitation coordination, performing the Damage Survey Report mission and other missions for technical assistance and providing water-supply support.

Kansas City District. A total of 52 federal levees, all of the federal levees in the Kansas City District's area of responsibility, were damaged. Of the 52 levees, only 27 sustained damage of a magnitude requiring PL 84-99 rehabilitation assistance beyond normal maintenance.

The event damaged nearly all non-federal levees on the Kansas, Missouri, Grand, Platte, Chariton, and Osage rivers. In addition, considerable damage was sustained on other tributaries. The damage equates to more than 800 levee segments. Of this number, only 110 units were eligible for PL 84-99 assistance.

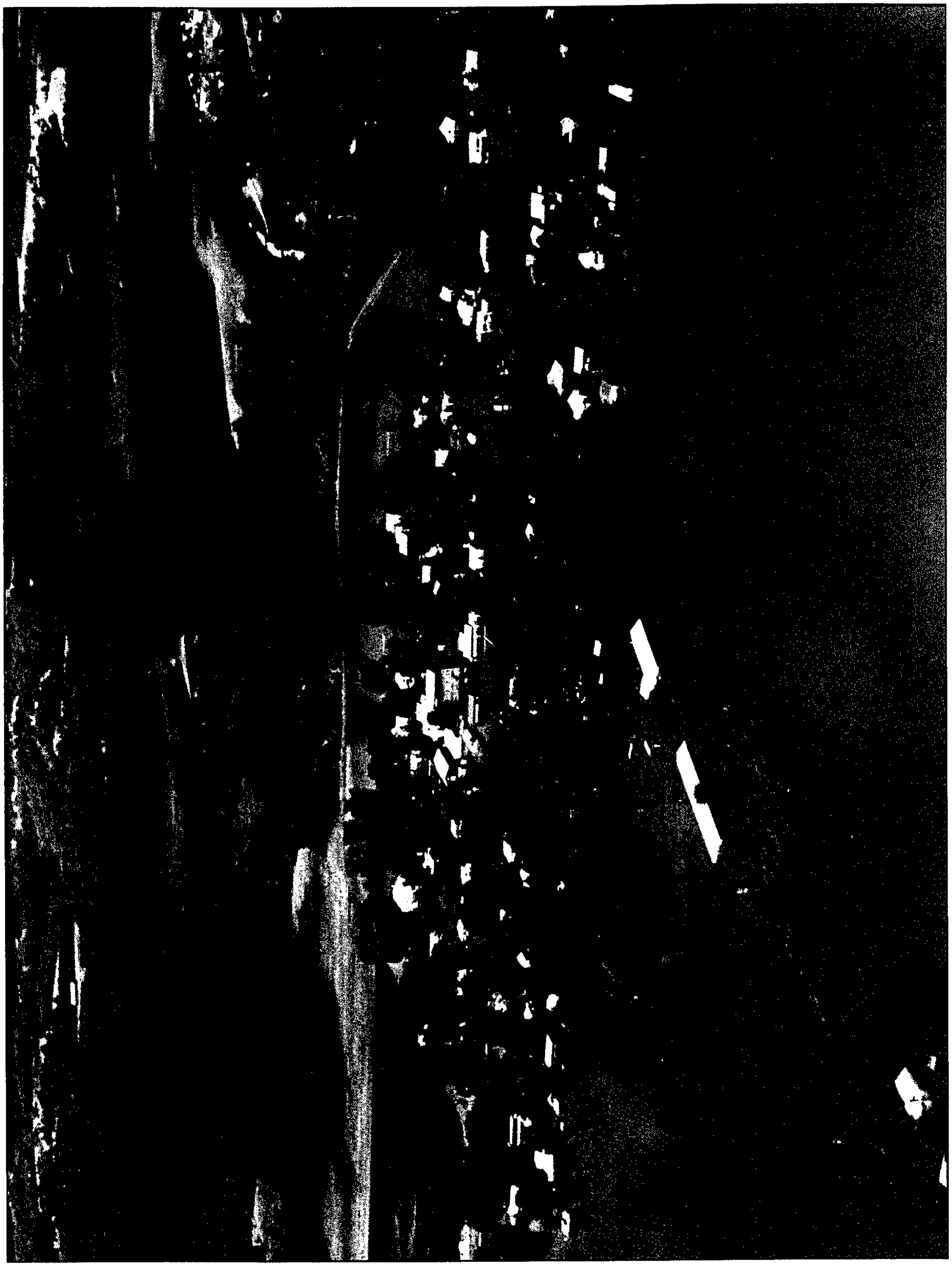
Levee districts experienced difficulty in getting landowners to agree to easements for areas where levees had to be moved back onto their land. Much of the damage caused such large holes that it was more economically feasible to go around the holes, eroding more precious farmland. Levee districts also had to provide their portion of the cost share with either cash outlay or in-kind work.

Rehabilitation efforts were administered by a combination of district, temporary duty, and Bureau of Reclamation personnel. Several circumstances adversely affected the rapid response efforts of the Corps of Engineers, and field investigations progressed slowly. Persistent rain kept many of the levees under water, making it impossible for the inspection teams to survey the damage until several months later.

Realignments and large cost-share portions caused delays and frustration for both levee district officials and landowners. Requirements for legal descriptions, rights of way, easements, and the "up front" cost share caused a greater impact on the levee districts than earlier.

To date, approximately 98 percent of all levee repairs are complete or underway. A number of levee repair completion dates may extend into the next calendar year for a variety of reasons. The main reason being the pump station restoration. Pump parts are difficult to obtain and some have to be custom made.

In summary, two levee districts in the North Central Division, three in the Missouri River Division, and two in the Lower Mississippi Valley Division are yet to be completed.



Foley, Mo., on the Missouri River.

Section VII
Lessons Learned

The flood-fighting activities taught many lessons to those involved. Many successes as well as many problems occurred. All gave valuable lessons that can be carried into the future. The following are some of these lessons.

- The Flood of 1993 tested Corps resources to an extent that had not been experienced in many years. Because of this, in several districts, few staff members had experience in dealing with a flood of this magnitude. Consequently, Corps staff was in an accelerated learning mode as the flood event developed. This was necessary and appropriate because it is not practical to have every possible need covered for events that occur only once each generation. The 1993 flood demonstrated that Corps staff, when put to the test, will respond with professional skills and personal dedication day after day, week after week, and month after month, until the emergency condition no longer exists. The lesson learned was the value in having district resources available to respond to the emergency.
- The responsible agencies for floodwalls and levees should be periodically informed of their responsibility to maintain a clear zone along floodwalls and levees to allow for inspection and to prevent roots from forming channels under or through the floodwall or levees. Where trees already exist, they need to be removed, including roots, to a specified depth and then the hole needs to be backfilled with impervious material.
- A video showing the filling, handling, and placing of sandbags and building ring levees or berms and use of plastic sheeting should be prepared and made available to appropriate organizations and personnel.
- Critical flood and post-flood news media "stories" and analysis pertaining to operating and performance of Corps projects need to be reviewed and their authors briefed by technical staff before those materials are released and presented.
- Better aerial photographs showing important towns, landmarks, and other facilities need to be taken in order to respond effectively to media requests.
- During the flooding, new techniques for flood fighting were used. Collapsible, portable floodwalls called "concertainers," for example, and rubber bladders filled with water (known as water tubes) were used. Flashboards were added to closure structures or floodwalls to prevent overtopping. In one instance a levee was cut open to protect a historic town downstream from flooding.
- This event broke historical stage and flow records in many areas and in some river reaches it exceeded the design flow of the existing flood-control structures. People have suggested that new labels, such as flood reduction, flood mitigation, or flood management, instead of flood control, be adopted. Floods cannot be 100 percent controlled. However, they can be greatly reduced and better managed with structural and non-structural improvements.
- One of the most significant shortcomings uncovered during flood preparation and flood fighting was the lack of a single, integrated electronic data-storage system. Emergency workers found themselves trying to match paper data with quad maps, regulation manuals, and profiles, for example. The use of a geographic information system (GIS) would allow easy update, the compilation of all pertinent data on a single sheet, and printouts of as many copies as required. A better method for transmitting current and accurate data in a timely manner to field activities regarding stages, flooded areas, and precipitation needs to be developed. A resource GIS data base could be the answer.
- Funds need to be programmed to update or otherwise revise the current stage-discharge and stage-damage relationships at Corps projects.
- Hydraulic data (e.g., high-water marks, rating curve and flow/stage/frequency relationships; geotechnical data/levee performance) and damage survey data (residential, commercial, industrial, and agricultural) must be collected immediately following the event.

Lessons Learned

- Some reservoir regulation plans developed for flood-control operation do not consider potential restrictions to the discharge capacity of the spillways or outlet works that could occur when the pool level is at or near the top of flood-control pool, or within the surcharge pool.
- Project features (outlet works, spillways, stilling basins, and downstream channels, for example) need to be maintained and repaired, so that the regulation plans stay current or warrant minor update.
- Critical infrastructures, such as water-treatment, sewage, and power-generating plants upstream and downstream of reservoirs, needed to be identified and their critical operating stages established.
- The Corps and the National Weather Service need to better coordinate for timely stage forecasts. Forecasts need to be coordinated between the involved offices.
- An easy method to distribute basic hydrologic data to the public, state and local governments, and higher Corps authority needs to be developed. This would minimize the time and effort needed to give out data which is usually performed by those actually running forecasts to determine reservoir releases.

Section VIII
Summary and Conclusions

Summary

The Flood of 1993 was an unusual and significant hydrometeorological event that devastated the Midwest. The flooding of the Mississippi and Missouri rivers resulted in the death of 47 people and caused between $15 to $20 billion in damage. The 1993 flood was distinctive from all other record floods in terms of its magnitude, severity, the resulting damage, and the season in which it occurred.

Excessive precipitation during April through July 1993 produced severe or record flooding in a nine-state area in the upper Mississippi River basin. Excessive precipitation also affected the Missouri River basin, adding to the flood's areal extent in three states. The rain storms that caused the Flood of 1993 were unique both in the size of the flooded area and in the fact that the storms resulted in the Mississippi and Missouri rivers cresting within the same week. As a result of severely high water along the Mississippi River below Dubuque, Iowa, barge traffic was suspended from late June until mid-August 1993.

Although, typically, floods occur in the spring, this flood occurred throughout the summer along the Mississippi and Missouri rivers. Flooding and water levels above the flood stage continued through the middle of September in many regions along the Mississippi River. In Hannibal, Mo., the Mississippi River remained above flood stage for more than six months.

Corps reservoirs along the upper Missouri River were able to store much of the excess runoff in Montana and North and South Dakota. However, on the Missouri River, downstream of Omaha, Neb., the reservoirs could not accommodate the record runoff. Portions of the Missouri River were above flood stage for several months. On the Mississippi River, there are only three reservoirs with significant storage capacity above St. Louis, Mo. These three reservoirs are located in Iowa and are operated by the Rock Island District for flood-reduction purposes. The Corps reservoirs were able to reduce the Mississippi River stage downstream of Keokuk, Iowa. Because of the prolonged runoff periods, the maximum crest reductions from the operation of Coralville, Saylorville, and Red Rock Reservoirs, amounted to 11 inches at Quincy, Ill., and Hannibal, Mo.

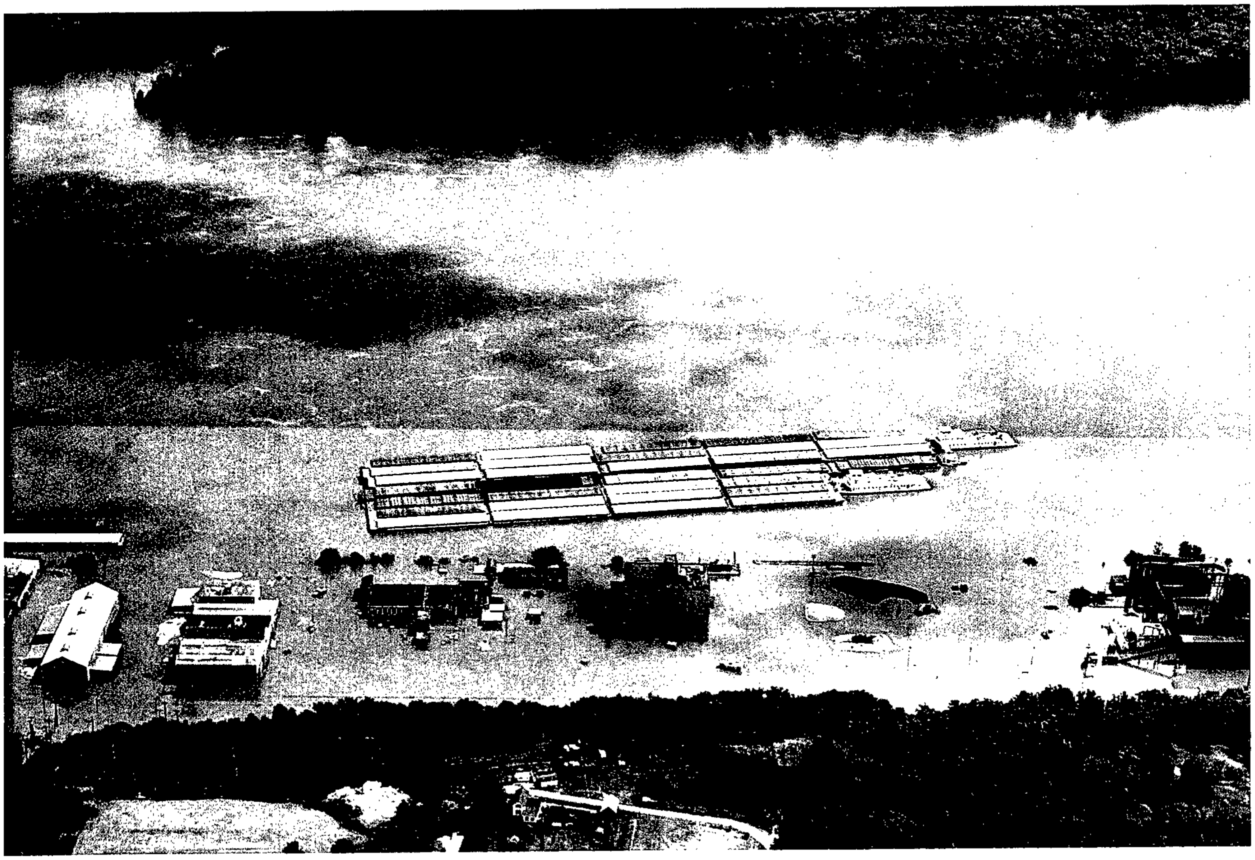
Even with these three reservoirs, the Flood of 1993 was in excess of a 100-year flood and, in some areas, perhaps even a 500-year flood. However, the people affected by this tremendous flood found little comfort in knowing that this was a very rare occurrence.

As the local, state, and federal agencies prepared for providing cleanup and other assistance, additional rains in late August and September continued, prolonging the soggy, wet conditions and causing further delays. After most flood waters had receded, heavy rainfall in mid-November resulted in a third disaster declaration on Dec. 1, 1993, for southeastern Missouri.

The Corps provided, on a priority basis, the emergency repairs of many federal and non-federal levees. The urgency concerned the need to try to provide closures to breached levees and rehabilitate pumping facilities to protect against eventual spring 1994 floods. The weather was cooperative in that a freeze-up did not occur until after the time it normally occurs in mid-December.

The weather also cooperated by producing few spring 1994 floods of only small magnitude. This has allowed for many additional repairs to take place. Some relocations of portions of towns—such as Valmeyer, Ill., and Chelsea, Iowa—are now taking place or getting underway.

The Corps of Engineers had no authority to fund flood-damage collection efforts for this Post-Flood Report. Therefore, no new flood-damage estimates were obtained. This report and its five appendices present some damage estimates developed by local, county, and state agencies. Recently released reports by the Federal Emergency Management Administration (FEMA) provide information concerning dollars paid out for assistance under its various authorities. These reports provide data for the states of Kansas, Illinois, Minnesota, Missouri, Nebraska, and Wisconsin. The



Towboat and barges stranded at flooded Lock and Dam 20 in Canton, Mo.

actual flood-damage information is expected to be provided in the Corps Flood Plain Assessment study, which is underway at this time. The report is to be released during the summer of 1995.

There are many accounts of the efforts of volunteers and the flood victims who helped during the flood and immediately afterward to try to restore their lives in the affected areas. Some of these accounts are documented in news articles in many of the local newspapers.

There are a number of publications and technical papers already written to date that document and further analyze the Flood of 1993. One of the most comprehensive reports to date was prepared by The Interagency Flood Plain Management River Committee, directed by Brigadier General Gerald E. Galloway. Their report entitled, Sharing the Challenge: Floodplain Management into the 21st Century was published on June 30, 1994. The committee had been appointed by the Administration's Floodplain Management Task Force. The report provides the committee's findings and recommendations for action.

The report represents the views of the review committee and is based on research and interactions with the federal, state, and local officers, businesses, interest groups, and individuals in and outside the upper Mississippi River basin. This six-month effort is now in the hands of the administration.

In addition, a number of Interagency Hazard Mitigation Team reports were prepared due to the federal disaster declarations resulting from the Flood of 1993, as required by FEMA. These reports provide actions that will reduce the potential for future flood loss. Hazard-mitigation measures are actions that individuals, organizations, and governments can take to reduce the effects of future disasters.

Another report, the National Oceanic and Atmospheric Administration's National Disaster Survey Report—The Great Flood of 1993—describes the Flood of 1993 as an unprecedented hydrometeorological event since the United States started to provide weather services in the mid-1800s.

The media brought this disastrous event into the living rooms of all U.S. citizens and provided it to the world almost on a daily basis throughout the entire flood event. No other natural disaster in U.S. history affected or touched so many lives for so long a duration as the Midwest Flood of 1993.

Conclusions

The Flood of 1993 was the worst flood ever experienced by the Midwest. From the standpoint of monetary loss, it was the worst ever in the United States because of its areal extent and long duration. Details of the damage caused by the flood have been identified. Effective mitigation measures now need to be implemented in order to reduce future loss of life and property.

Flooding from this event caused major highways, bridges, and rail lines to be closed for a long period of time. Officials from these entities now will be redesigning their facilities to protect against future floods of this magnitude. Navigation was shut down on the Mississippi River (see Table 6), closing a main transportation artery to the Midwest. In the aftermath, major efforts were carried out to restore the lock operations on the Mississippi River. Many wastewater and water-supply facilities were disrupted or even totally shut down. Officials of these facilities are redesigning them to provide greater flood protection. Cost-effective measures for hazard mitigation are expected to be incorporated into the repair cost of damaged public facilities.

Damage to communities was extensive. Many are reassessing their situation and seeking relocation opportunities. Officials and owners are still evaluating the relocation of residential structures that were heavily damaged.

Major public power utilities sustained damage to electrical transmission and distribution systems. Many of these damaged utilities will need to be relocated.

Finally, the damage to farmland and pastures was severe. Some acreage may not be restored for agricultural purposes.

The federal floodplain management policy is being reassessed. Possibilities for returning some of the flood plain to their natural state—particularly to wetlands—will be studied as part of the Corps "Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries" report. The impacts of the Flood of 1993 are, therefore expected to provide a planned approach to drastically reduce the flood damage of future large flood events.

Flooded railroad bridge over the Missouri River near Glasgow, Mo.

Glossary

Acre-foot: An area of one acre covered with water to a depth of one foot. One acre-foot is 43,560 cubic feet or 325,851 gallons.

Agricultural levee: A levee that protects agricultural areas where the degree of protection is usually less than that of an urban levee.

Antecedent: Having occurred prior to the time under consideration.

Authorization: House and Senate Public Works Committee resolutions or specific legislation which provide the legal basis for conducting studies or constructing projects. The money necessary for accomplishing the work is not a part of the authorization, but must come from an appropriation by Congress.

Backwater: The water surface of a stream raised above its normal level by a natural or artificial obstruction.

Bank and channel stabilization: The process of preventing bank erosion and channel degradation.

Basin: Drainage area of a lake or stream as: river basin.

By-channel: A channel formed around the side of a reservoir past the end of the dam to convey flood discharge from the stream above the reservoir into the stream below the dam.

Channel: A natural or artificial waterway which periodically or continuously contains flowing water.

Closure structure: A movable structure built along low points of a levee or floodwall such as a street or railroad intersection to prevent floodwaters from flooding the area protected by the levee or floodwall.

Confluence: The place where streams meet.

Control dam: A dam or structure with gates to control the discharge from the upstream reservoir or lake.

Conveyance: A measure of the flow carrying capacity of a channel section.

Crib wall: A near vertical wall created by a framework of structural ties filled with soil.

Cross section: A plot which depicts the shape of the channel in which a stream flows.

Dam: A barrier constructed across a valley for impounding water or creating a reservoir.

Damages prevented: The difference between damages occurring without the project and the damages with the project in place.

Degree of protection: The magnitude of protection that a flood control measure is designed for, usually expressed as a statistical estimate of how often such a flood could occur, i.e. "a 100-year flood."

Depth of flow: The vertical distance from the bed of a stream to the water surface.

Deposition: The mechanical or chemical process through which sediments accumulate in a (temporary) resting place. The raising of a stream bed by settlement of moving sediment that may be due to local changes in the flow such as during a flood event.

Dike: An embankment to confine or control water and/or soil.

Discharge: The volume of fluid passing through a cross section of a stream per unit time.

Diversion channel: (1) An artificial channel constructed around a town or other point of high potential for flood damages to divert floodwater from the main channel to minimize flood damages. (2) A channel carrying water from a diversion dam.

Drainage basin: The area tributary to or draining into a lake, stream, or measuring site.

Dredged material: The material removed in excavating or dredging in access canals, boat or navigation channels, drainage ditches, and lakes.

Earthfill dam: A dam in which the main section is composed principally of earth, gravel, sand, silt, and clay.

Environmental Assessment (EA): A planning report which presents the first thorough examination of alternative plans that positively demonstrates that the environmental and social consequences of a Federal action were considered. If the EA concludes that the proposal is a major Federal action significantly impacting on the quality of the human environment, an environmental impact statement will be required.

Environmental Impact Statement (EIS): A report required by Section 102(2)(c) of Public Law 91-190 for all Federal actions which significantly impact on the quality of the human environment. The EIS is a detailed and formal evaluation of the favorable and adverse environmental and social impacts of a proposed project and its alternatives.

Erosion: The wearing of a land surface by detachment and movement of soil and rock fragments through the action of moving water and other geological agents.

Feasibility study: An evaluation of a water resources problem to determine if a proposed work is technically, environmentally, and economically sound.

Federal levee: A levee system constructed by a federal agency such as the U.S. Army Corps of Engineers, the Soil Conservation Service, or the Bureau of Reclamation.

Flank levee: A levee constructed nearly perpendicular to the streamflow.

Flat pool: The pool on the upstream side of navigation lock and dam where the water surface level is nearly horizontal or has a very mild slope.

Flood capacity: The flow carried by a stream of floodway at bank-full water level. Also, the storage capacity of the flood pool at a reservoir.

Flood crest: The highest or peak elevation of the water level during a flood in a stream.

Flood plain: Valley land along the course of a stream which is subject to inundation during periods of high water that exceed normal bank-full elevation.

Floodproofing: Techniques for preventing flood damage to the structure and contents of buildings in a flood hazard area.

Floodwall: Wall, usually built of reinforced concrete, to confine streamflow to prevent flooding.

Freeboard: (1) Vertical distance between the normal maximum level of the surface of the liquid in a conduit, reservoir, tank, canal, etc., and the top of the sides of the conduit, reservoir, canal, etc. (2) An allowance in vertical distance above the design water surface level.

Frequency: The number of repetitions of a random process in a certain time period.

Gage: A device used for measuring environmental parameters (i.e., water levels, precipitation, temperature, water quality parameter, etc.)

Gaging station: A location on a stream where one or more variables are measured to record discharge and other parameters.

Gravity drainage outlets: (1) Outlets for gravity drains such as tiles, perforated conduits, etc., servicing an agricultural area and discharge into a drainage ditch. (2) Pipe, culvert, etc., used for dewatering ponded water by gravity from leveed areas.

Groin: A wall-like structure built perpendicular to the shore to trap sand and prevent beach erosion.

Habitat: The total of the environmental conditions which affect the life of plants and animals.

Headwaters: (1) The upper reaches of a stream near its source. (2) The region where groundwaters emerge to form a surface stream. (3) The water upstream from a structure.

Historic flows: The collection of recorded flow data for a stream during the period of time in which stream gages were in operation.

Hydraulic model: An analytical or physical scale model of a river used for engineering studies.

Hydraulics: The study and computation of the characteristics (e.g. water surface elevation, velocity, slope) of water flowing in a stream, river, or man-made channel.

Hydrograph: A graph showing for a given point on a stream or channel, the discharge, water surface elevation, stage velocity, or other property of water with respect to time.

Hydrology: The studies of the properties, distribution, and circulation of water on the surface of the land, in the soil, and in the atmosphere.

Impoundment: A body of water formed by collecting water, as a dam.

Left or right bank of river: The left-hand or right-hand bank of a stream when the observer faces downstream.

Levee: A dike or embankment, generally constructed close to the banks of the stream, lake or other body of water, intended to protect the land-slide from inundation or to confine the streamflow to its regular channel.

Level of protection: Same as degree of protection.

Lift: The difference in elevation between the upstream and downstream water surface levels in a lock and dam system.

Lift lock: A canal lock serving to lift a vessel from one reach of water to another such as from the downstream side to the upstream side of a navigation lock and dam system.

Lift span bridge: A bridge having a movable span which remains horizontal while being lifted vertically by cables arranged through towers at both ends.

Lift station: A small wastewater pumping station that lifts the wastewater to a higher elevation when the continuance of the sewer at reasonable slopes would involve excessive depths of trench.

Lock: An enclosed part of a canal, waterway, etc., equipped with gates so that the level of the water can be changed to raise or lower from one level to another.

Lock operation: Locks fill and empty by gravity, with no pumps required to raise or lower the water level. To raise the water level, valves are opened above the upper gates and water flows into the lock through tunnels in both lock walls. This process is reversed to lower water in the lock. Valves are opened below the lower gates and water drains out of the lock through the tunnels. Gates at both ends of the lock open and close electrically after the proper water level has been reached.

Meander: The name given to the winding course of a stream or river. The shape and existence of the bends are a result of alluvial process and are not determined by the nature of the terrain through which the stream flows.

Meteorology: The science that deals with the atmosphere and its phenomena, especially with weather and weather forecasting.

Miter gates: A type of gate commonly used to trap water in a lock chamber.

Model: A representation of a physical process or device that can be used to predict the

Mouth of river: The exit or point of discharge of a stream into another stream, lake, or the sea.

NGVD: Acronym for National Geodetic Vertical Datum. A vertical datum plane reference which has replaced mean sea level.

Non-federal levee: Any levee or levee system constructed by a non-federal agency, which is operated and maintained by a public sponsor.

Normal precipitation (or temperature): The average precipitation over the most recent three decades based on a local or regional station, for which long-term records are available.

1% Flood: This is the same as a 100-year flood and is a flood which has a 1% chance of occurrence in any given year.

Overbank: The area in a river which lies between the bank of the main channel and the limits of the floodplain.

Oxbow lake: A lake formed in the meander of a stream, resulting from the abandonment of the meandering course due to the formation of a new channel course.

Planform: The form and size of a channel and overbank features as viewed from above.

Pile dike: A dike constructed of posts of similar piling driven into the soil.

Ponding area: An area reserved for collecting excess runoff preparatory to being discharged whether by gravity or by pumping from a leveed area.

Pool: A small and rather deep body of quiet water as: water behind a dam.

Private levee: A levee constructed, owned, and maintained by one or more individual land owner(s).

Pumping station: A structure containing pumps which is used to evacuate runoff from behind levees during periods when high river levels prevent gravity drainage.

Reach: A length, distance, or a leg of a channel or other watercourse.

Recurrence interval: The statistically derived probability of occurrence of a flood event converted to a time interval (e.g. a 1% change flood = 100 year flood).

Rehabilitation: A major repair job. Usually involves considerable reconstruction of already existing structures.

Reservoir: A pond, lake, tank, basin, or other space, either natural or created in whole or in part by the building of a structure such as a dam, which is used for storage, regulation, and control of water for flood control, power, navigation, recreation, etc.

Retarding dam: A dam used to reduce the flood-flow of a stream through temporary storage.

Revetment: (1) A facing of stone, concrete, sand-bags, etc., to protect a streambank of earth from erosion. (2) A retaining wall.

Riprap: A layer, facing, or protective mound of randomly placed stones to prevent erosion, scour, or sloughing of a structure or embankment.

River basin: A water resource basin is a portion of a water resource region defined by a hydrological boundary which is usually the drainage area of one of the lesser streams in the region.

River region: A water resource is a major hydrologic area consisting of either the drainage area of a major river, such as the Missouri River, or the combined drainage areas of a series of streams.

River tow: An assemblage of one or more barges propelled by a towboat in a riverine waterway.

Rock dike: An embankment built principally of rock.

Runoff: Flow that is discharged from an area by stream channels; sometimes subdivided into surface runoff, groundwater runoff, and seepage.

Sandbag closure: A temporary closure structure consisting of sandbags. This closure may be found where a levee or floodwall has a sudden break in grade such as in a street crossing. Sandbags are used to close the street in times of high water to prevent flooding.

Scour: The enlargement of a cross section of a stream by the removal of boundary material through the action of fluid motion.

Sediment: A collective term meaning an accumulation of soil, rock, and mineral particles transported or deposited by flowing water.

Sediment load: The total sediment composed of suspended load and bed load transported by a stream. The suspended load is composed of fine sediment transported in suspension while bed load is composed of relatively coarse material transported along or near the bottom.

Sediment sample: A quantity of water-sediment mixture or deposited sediment that is collected to characterize some property of the sampled medium.

Sedimentation: A process that consists of five steps: (1) weathering, (2) erosion, (3) transportation, (4) deposition, and (5) diagenesis, or consolidation into rock. Also refers to the gravitational settling of suspended particles.

Sedimentation basin: A basin or tank in which water or wastewater containing settleable solids is retained to remove (by gravity) a part of the suspended matter.

Self-liquidating facilities: Facilities provided by local interests at a project site in addition to facilities which are a part of the federally cost-shared project features. These facilities are considered to be self-liquidating in that they can be paid for through user fees charged to the public. These facilities might include such things as a public wharf, mooring facilities, parking areas, etc.

Shoal area: Patches of sand, gravel, or other hard bottom lying at shallow depths.

Sill: (1) A horizontal beam forming the bottom of an entrance to a lock. (2) Also, a low submerged dam like structure built to control riverbed scour and current speeds.

Slack-water area: (1) In tidal waters, the area where tidal current velocity is at a minimum; especially the moment when a reversing current changes direction and its velocity is zero. (2) In streams, a place where there is very little current.

Slope: A portion of ground or a stream having an upward or downward inclination.

Slough: (1) A small muddy marshland or tidal waterway, which usually connects other tidal areas. (2) A tide land or bottom land creek. A side channel or inlet, as from a river or bayou, that may be connected at both ends to a parent body of water.

Spillway: A waterway of a dam or other hydraulic structure used to discharge excess water to avoid overtopping of a dam.

Spoil material: See Dredged material.

Spot dikes: A series of small dikes or levees filling low spots along a bank.

Stage: The elevation of the water surface above or below an arbitrary datum.

Stage-Discharge (rating) curve: A graph that defines the relationship between discharge and water surface elevation at a given location.

Standard project flood: A flood that may be expected from the most severe combination of meteorological and hydrological conditions that are reasonably characteristic of the geographical region involved, excluding extremely rare combinations.

Stem of a river: The primary axis of the river; the main channel.

Stop-log closure: Logs, planks, cut timber, steel, or concrete beams fitting into the guides between walls or piers to close an opening in a levee, dam, or conduit to the passage of water. The logs are usually placed one at a time.

Stream discharge: The volume of flow passing a stream cross section per unit time.

Stream gage: A device that measures and records flow characteristics such as water surface elevation at a specific location on a stream. Sediment transport measurements are usually made at stream gage sites.

Stream profile: A plot of the elevation of a stream bed or water surface versus distance along the stream.

Swale: (1) A slight depression, often wet and covered with vegetation. (2) A wide, shallow ditch, usually grassed or paved.

Swing span bridge: This is the span of a bridge across a navigable stream that rotates to allow tall ships to pass through the bridge.

Synopsis: A condensed statement or outline.

Tailwater: The water surface elevation downstream from a structure such as below a dam, weir, or drop structure.

Tainter gate: A semi-circular gate which opens and closes through pivoting on a shaft and is used to control the flow of water over a spillway.

Tributary: A stream or other body of water that contributes its water to another stream or body of water.

Uncontrolled spillway: An overflow spillway having no control gates.

Urban levee: Levees which provide a high degree of flood protection (50- or 100-level or greater) to predominantly urbanized areas.

Vertical lift gate: A gate that moves vertically in slots or tracks in piers and consists of a skin plate and horizontal girders which transmit the water load into the piers.

Water shed: The whole surface drainage area that contributes water to a collecting river or lake.

Wing dam: A wall, crib, row, pilings, stone jetty, or other barrier projecting from the bank into a stream for protecting the bank from erosion, arresting sand movement, or for concentrating the low flow of a stream into a smaller channel.

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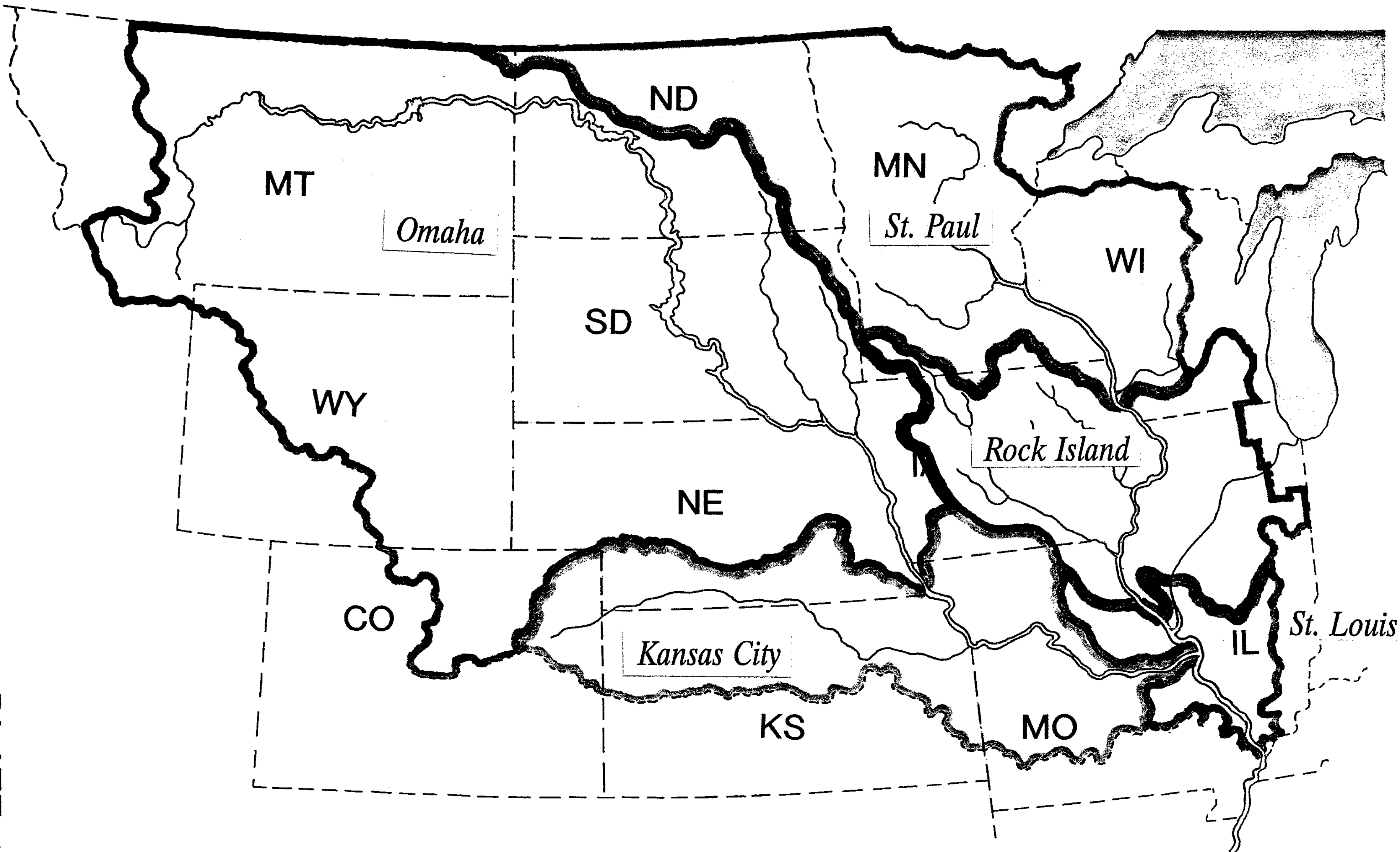
Lemberger, Michael W., Keokuk, Iowa. Aerial photograph copyright 1993.

Conversion Table
For Units In This Report

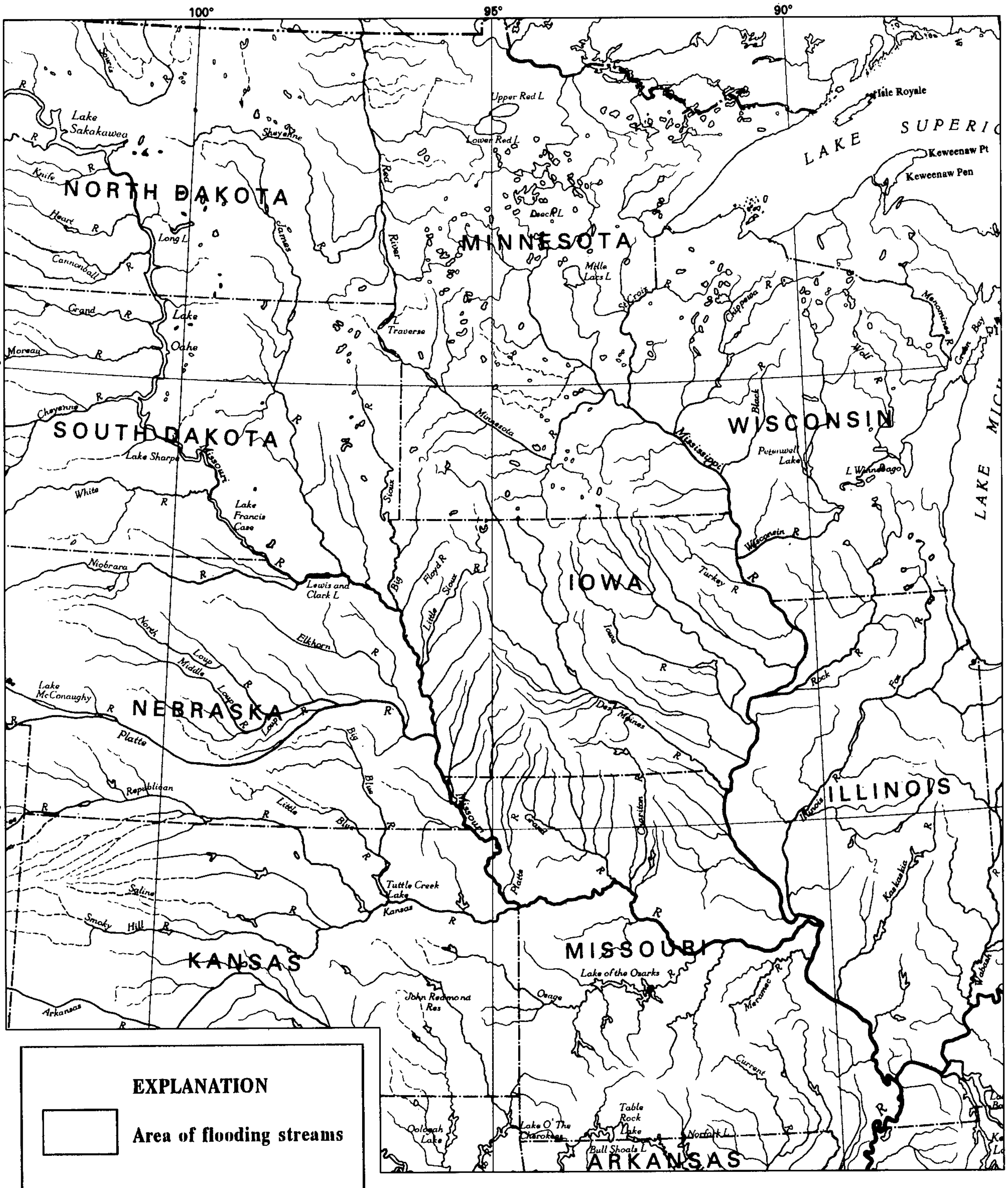
1 inch	=	2.54 cm
1 foot	=	30.48 cm
1 acre-foot	=	1,233.5 m^3
1 $ft.^2$	=	0.093 m^2
1,000 cfs	=	28.317 m^3/sec
1 mile = 5,280 ft.	=	1.609 km
1 square mile	=	259.0 hectares
1 acre	=	0.405 hectare
1 ton	=	907.2 Kgs

Plates



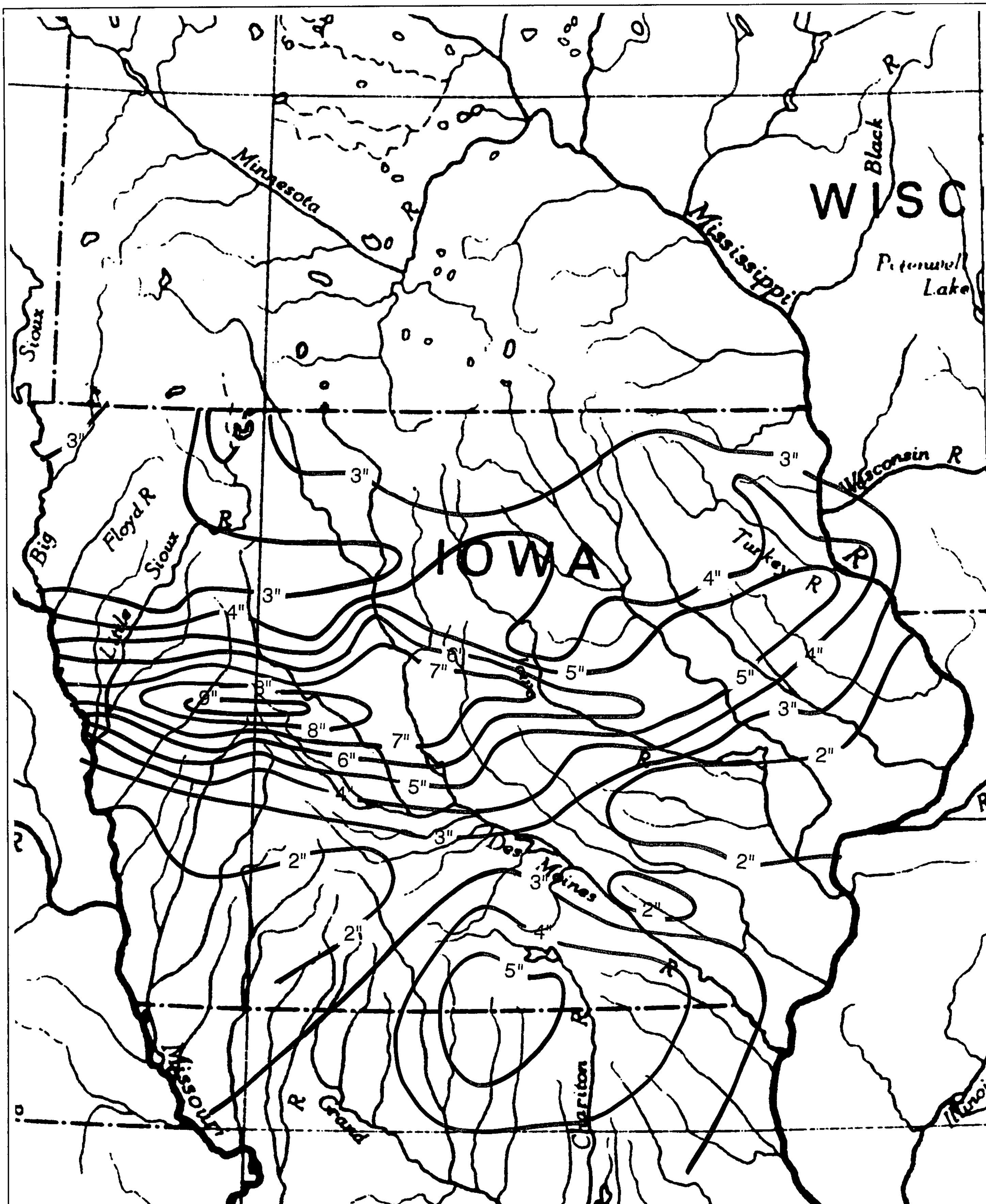
Corps of Engineers Districts and their boundaries.

PLATE 1



NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
WISCONSIN
IOWA
NEBRASKA
ILLINOIS
KANSAS
MISSOURI
ARKANSAS
LAKE SUPERIOR
LAKE MICHIGAN
100°
95°
90°
45°
40°
EXPLANATION
Area of flooding streams
0 100 200 MILES
0 100 200 KILOMETERS

PLATE 2



Explanation: —7— Line of equal rainfall for July 8-10, 1993—Interval 1 inch

PLATE 3

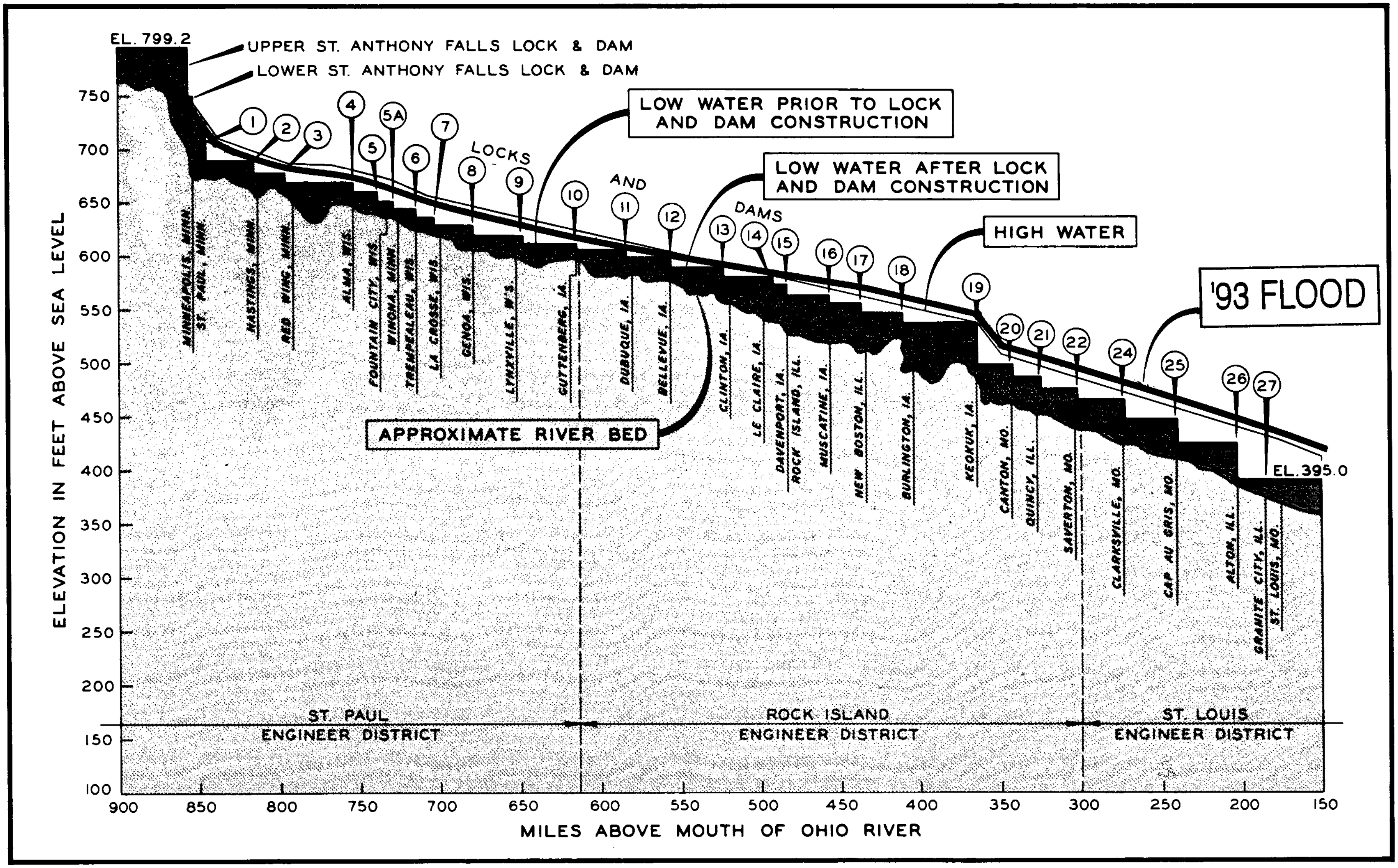
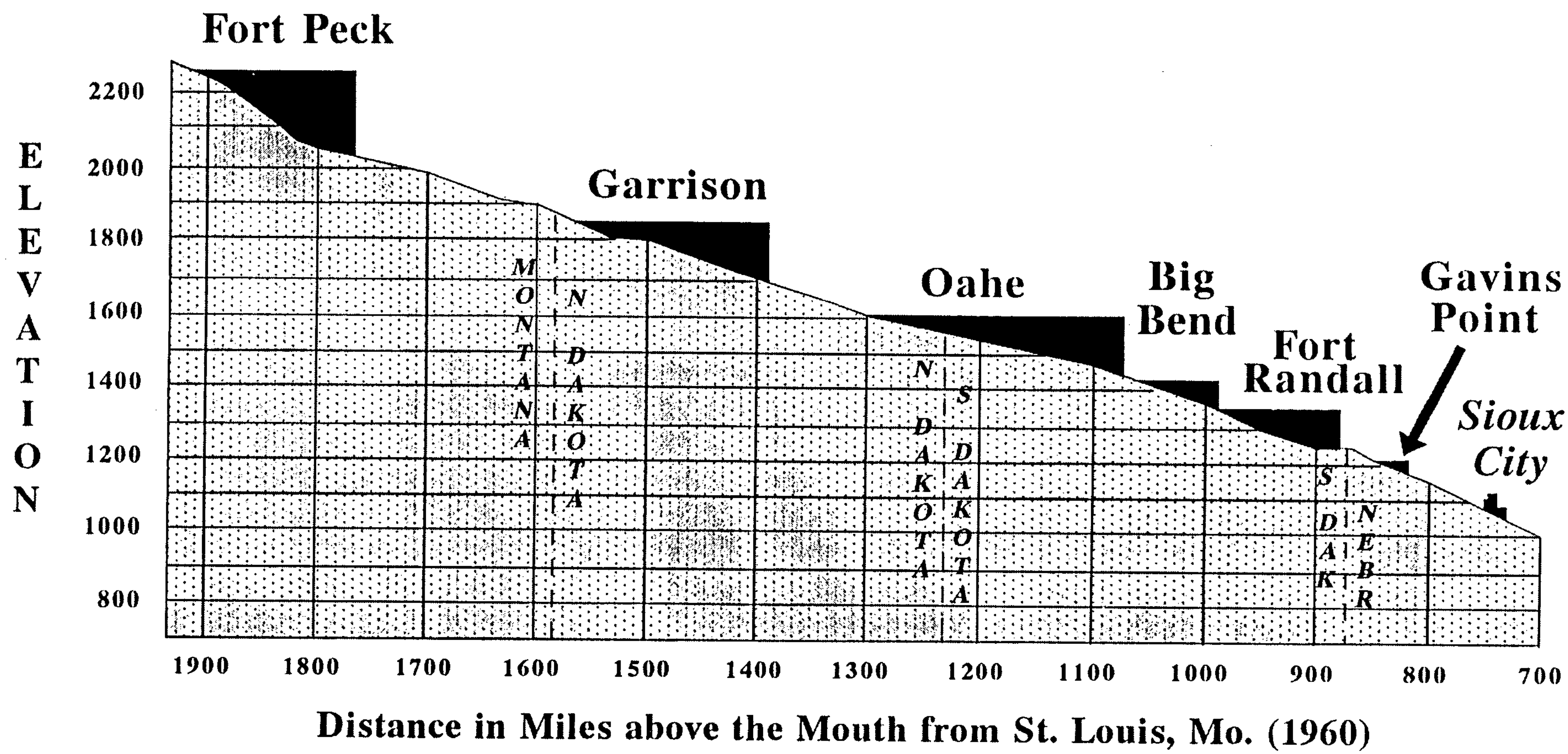
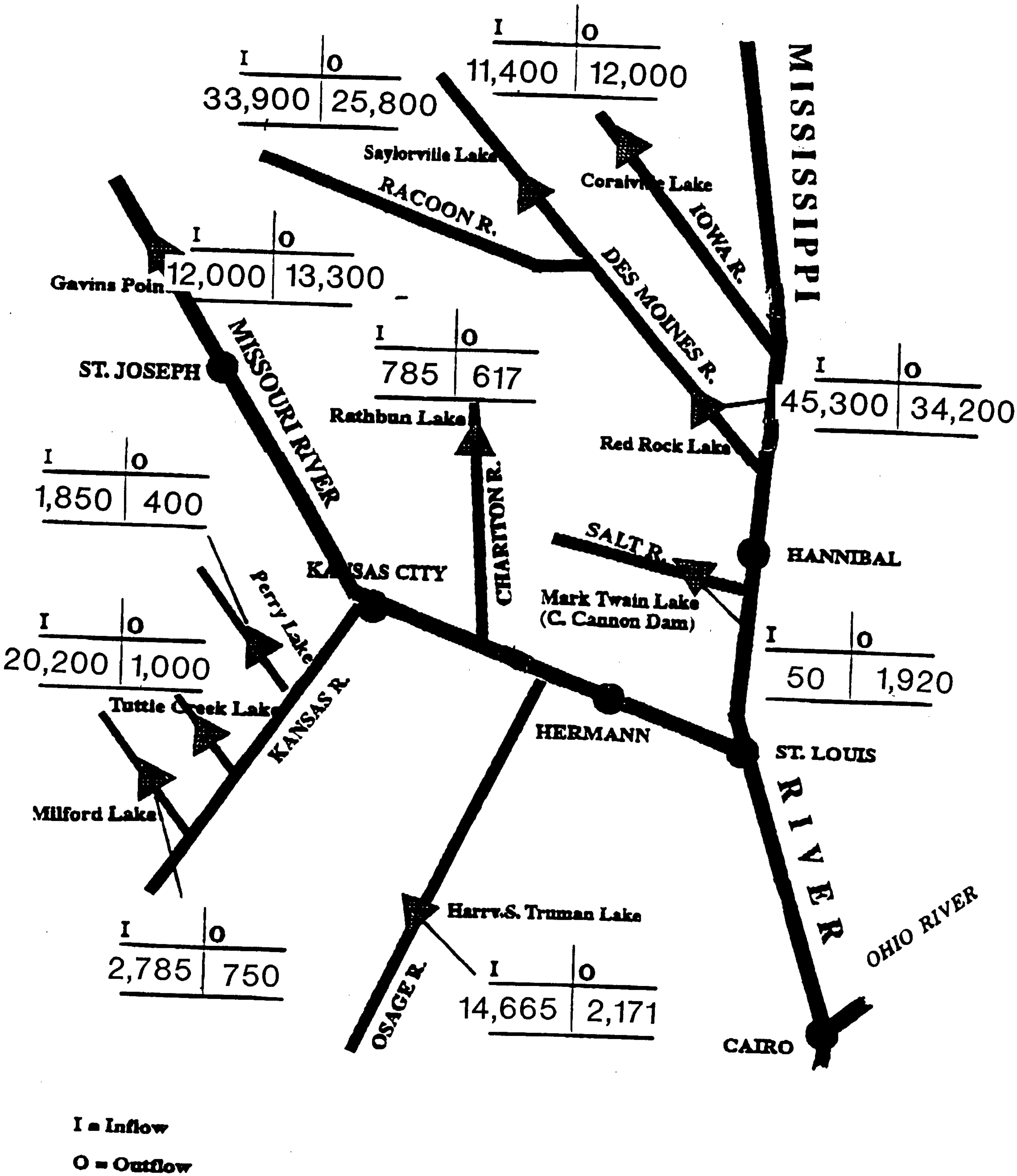

EL. 799.2
UPPER ST. ANTHONY FALLS LOCK & DAM
LOWER ST. ANTHONY FALLS LOCK & DAM
LOW WATER PRIOR TO LOCK AND DAM CONSTRUCTION
LOW WATER AFTER LOCK AND DAM CONSTRUCTION
HIGH WATER
'93 FLOOD
LOCKS AND DAMS
1
2
3
4
5
5A
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
24
25
26
27
MINNEAPOLIS, MINN.
ST. PAUL, MINN.
HASTINGS, MINN.
RED WING, MINN.
ALMA, WIS.
FOUNTAIN CITY, WIS.
WINONA, MINN.
TREMPEALEAU, WIS.
LA CROSSE, WIS.
GENOA, WIS.
LYNXVILLE, W.S.
GUTTENBERG, IA.
DUBUQUE, IA.
BELLEVUE, IA.
CLINTON, IA.
LE CLAIRE, IA.
DAVENPORT, IA.
ROCK ISLAND, ILL.
MUSCATINE, IA.
NEW BOSTON, ILL.
BURLINGTON, IA.
KEOKUK, IA.
CANTON, MO.
QUINCY, ILL.
SAVERTON, MO.
CLARKSVILLE, MO.
CAP AU GRIS, MO.
ALTON, ILL.
GRANITE CITY, ILL.
ST. LOUIS, MO.
EL. 395.0
APPROXIMATE RIVER BED
ST. PAUL ENGINEER DISTRICT
ROCK ISLAND ENGINEER DISTRICT
ST. LOUIS ENGINEER DISTRICT
ELEVATION IN FEET ABOVE SEA LEVEL
750
700
650
600
550
500
450
400
350
300
250
200
150
100
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
MILES ABOVE MOUTH OF OHIO RIVER

PLATE 4



Profile of Missouri River Main Stem Reservoir System



SCHEMATICS OF RESERVOIR RELEASES 1 JULY 93
Upper Mississippi and Lower Missouri River Basin

PLATE 6

THE GREAT JUNE THRU AUGUST 1993 FLOOD

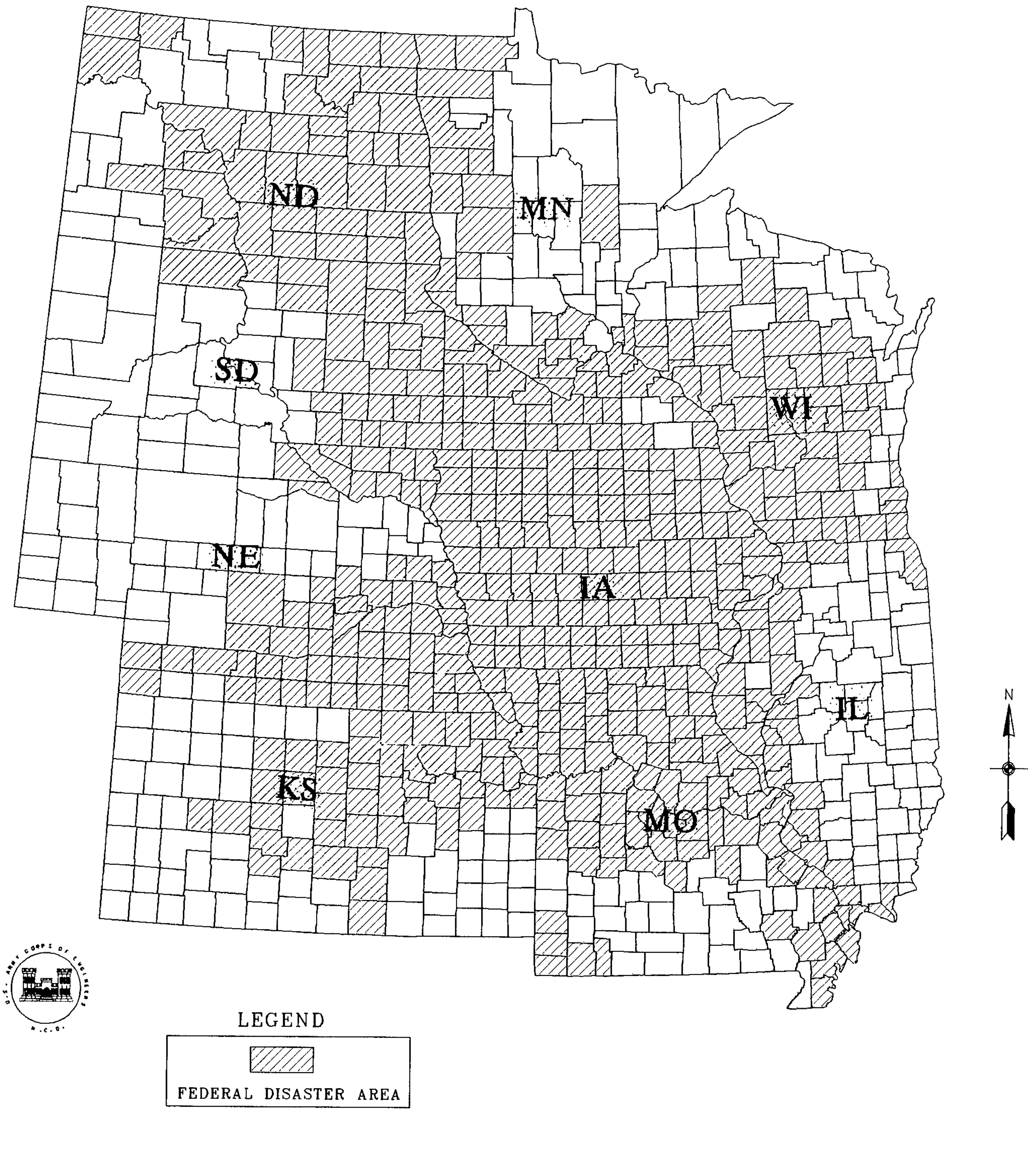
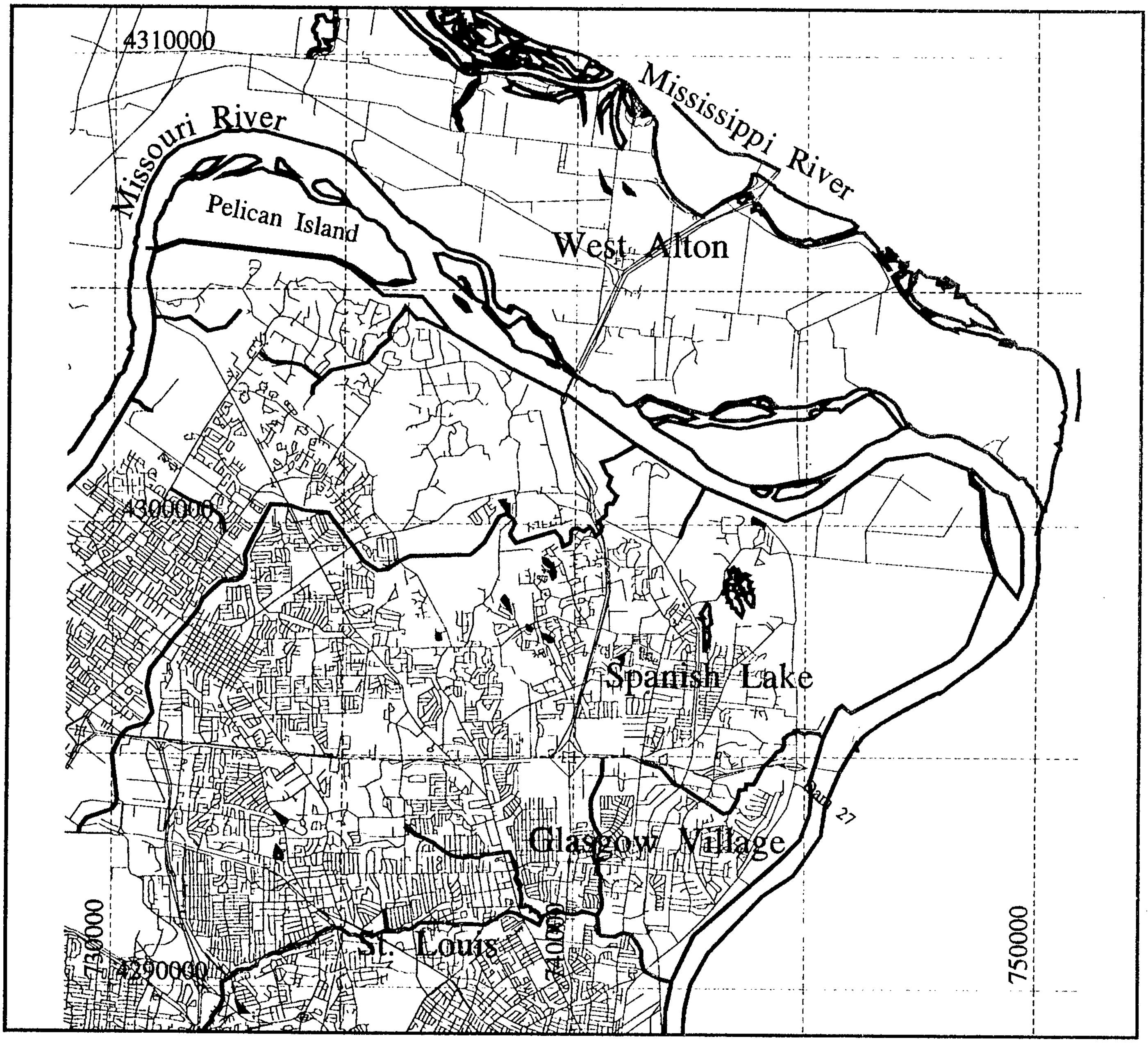


PLATE 7

	FEMA ASSISTANCE					
COUNTY	Housing Assistance	Individual Family Grants	Total Individual Assistance	Total Public & Private Non-Profit	Total Public & Non-Profit & Individual Assistance	Total Small Business Administration Loans
IOWA:						
• Adair	38,330	1,504	39,834	318,532	358,366	22,100
• Audubon	56,960	8,779	65,738	246,367	312,105	29,000
• Buena Vista	7,885	345	8,230	595,722	603,952	16,400
• Carroll	245,717	32,134	277,851	523,900	801,751	98,400
Cass	68,584	608	69,192	227,474	296,666	16,900
Cherokee	188,931	24,761	213,692	140,232	353,924	82,100
Clay	208,873	12,348	221,221	0	221,221	187,400
Crawford	288,154	103,935	392,088	1,657,548	2,049,636	236,800
Dickinson	433,393	35,103	468,496	849,845	1,318,341	206,600
• Emmet	131,565	6,634	138,198	0	138,198	89,100
Fremont	32,273	7,268	39,541	736,536	776,077	10,600
• Guthrie	80,063	13,750	93,813	427,787	521,600	32,700
Harrison	127,494	35,787	163,281	1,423,800	1,587,081	163,900
Ida	452	0	452	22,695	23,147	0
Lyon	131,877	17,795	149,672	563,305	712,977	105,300
Mills	135,406	14,134	149,541	241,500	391,041	160,700
Monona	158,789	13,849	172,637	439,355	611,992	60,700
• Montgomery	38,425	9,615	48,040	467,219	515,259	4,100
O'Brien	35,582	1,531	37,113	64,019	101,132	2,100
Osceola	66,542	12,554	79,096	99,544	178,640	51,400
• Page	148,003	19,310	167,313	432,655	599,968	67,100
• Palo Alto	179,694	16,478	196,172	374,717	570,889	85,900
Plymouth	9,465	1,256	10,721	109,153	119,874	0
Pottawattamie	2,128,554	385,020	2,513,574	1,716,206	4,229,780	1,160,900
• Sac	2,312	443	2,755	24,542	27,297	0
Shelby	181,520	122,502	304,022	531,782	835,804	169,000
Sioux	52,777	14,480	67,257	176,599	243,856	9,300
Woodbury	18,328	590	18,918	1,143,306	1,162,224	5,700
SUBTOTAL	**5,195,947**	**912,513**	**6,108,460**	**13,554,340**	**19,662,800**	**3,074,200**
MINNESOTA:						
• Jackson	212,243	16,012	228,255	725,969	954,224	160,900
• Lincoln	162,748	11,865	174,613	702,294	876,907	62,000
• Murray	108,025	22,025	130,050	523,576	653,626	299,902
• Nobles	315,993	72,688	388,681	951,052	1,339,733	398,000
• Pipestone	174,402	49,502	223,904	814,041	1,037,945	237,400
Rock	289,719	35,459	325,178	1,373,613	1,698,791	216,500
SUBTOTAL	**1,263,130**	**207,551**	**1,470,681**	**5,090,545**	**6,561,226**	**1,374,702**
MISSOURI:						
• Atchison	455,380	141,538	596,918	878,560	1,475,478	228,900
• Holt	1,036,838	569,822	1,606,660	861,219	2,467,879	360,200
SUBTOTAL	**1,492,218**	**711,360**	**2,203,578**	**1,739,779**	**3,943,357**	**589,100**
NEBRASKA:						
• Adams	16,347	694	17,041	742,565	759,606	33,000
Boone	8,123	1,493	9,615	71,358	80,973	0
Boyd	45,252	7,475	52,726	381,080	433,806	11,600
Buffalo	86,769	150,001	236,770	659,782	896,552	279,100
Burt	9,855	0	9,855	164,699	174,554	0
• Butler	1,891	391	2,282	186,062	188,344	0
Cass	301,065	216,842	517,907	1,156,941	1,674,848	261,800

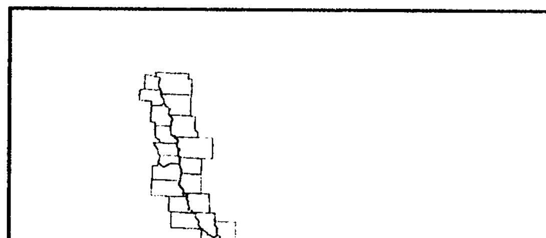
Sample of FEMA damage assistance summaries ($000) by counties

PLATE 8



Legend

- Roads
- Railroads
- Hydrography
- Inundation Areas
- 5,000 Meter Grid



St. Louis, MO

K9g5

U. S. Army
Corps of Engineers
Remote Sensing/
GIS Center

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PLATE 9